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Technical Training

SATELLITE, WIDEBAND AND TELEMETRY SYSTEMS (SWATS) APPRENTICE COURSE (Block 14)

Special Purpose SWATS Ground Terminals

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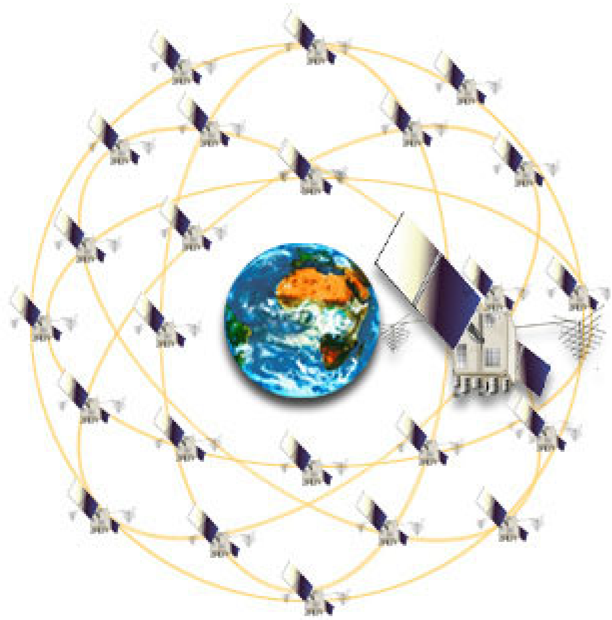
Block 14, Chapter 1
GLOBAL POSITIONING SYSTEM



INTRODUCTION

Lately you may have heard of a system called Global Positioning System (GPS). It gained significance in meaning during recent operations in Desert Shield and Desert Storm. But what is GPS? Basically, it is a satellite-based system for navigation. It uses earth-orbiting satellites to transmit navigational information to a wide variety of users on land, at sea, or in the air.

Although GPS is a fairly recent development, the idea of using satellites for navigation purposes did not originate with the GPS system. As early as 1970, the U.S. Navy had already successfully developed and deployed two such systems, known as Transit and Timation. These systems were crude but they worked. They were hampered with some serious limitations, such as limited availability to users, or restriction to two-dimensional (latitude and longitude only) navigation.

In the early 1970s, the Department of Defense issued a directive establishing the requirement to plan, design, and develop a new satellite navigation system - one that would eliminate the problems of the earlier systems. This proposed system would provide accurate, continuous coverage of the entire earth, and would make possible three-dimensional (latitude, longitude and altitude) navigation as well. GPS is that system.

Purpose

The mission of GPS is to provide all weather, three dimensional positioning (longitude, latitude and altitude), velocity, timing and nuclear detonation information to properly equipped air, land, sea and space based users. The system provides military and civilian users with highly accurate, continuous (24 hours per day) navigation data references to support a wide scope of applications.

Major Components

GPS has three major Segments, (see Figure 1-1): Space Segment, User Segment and Operational Control Segment (OCS).

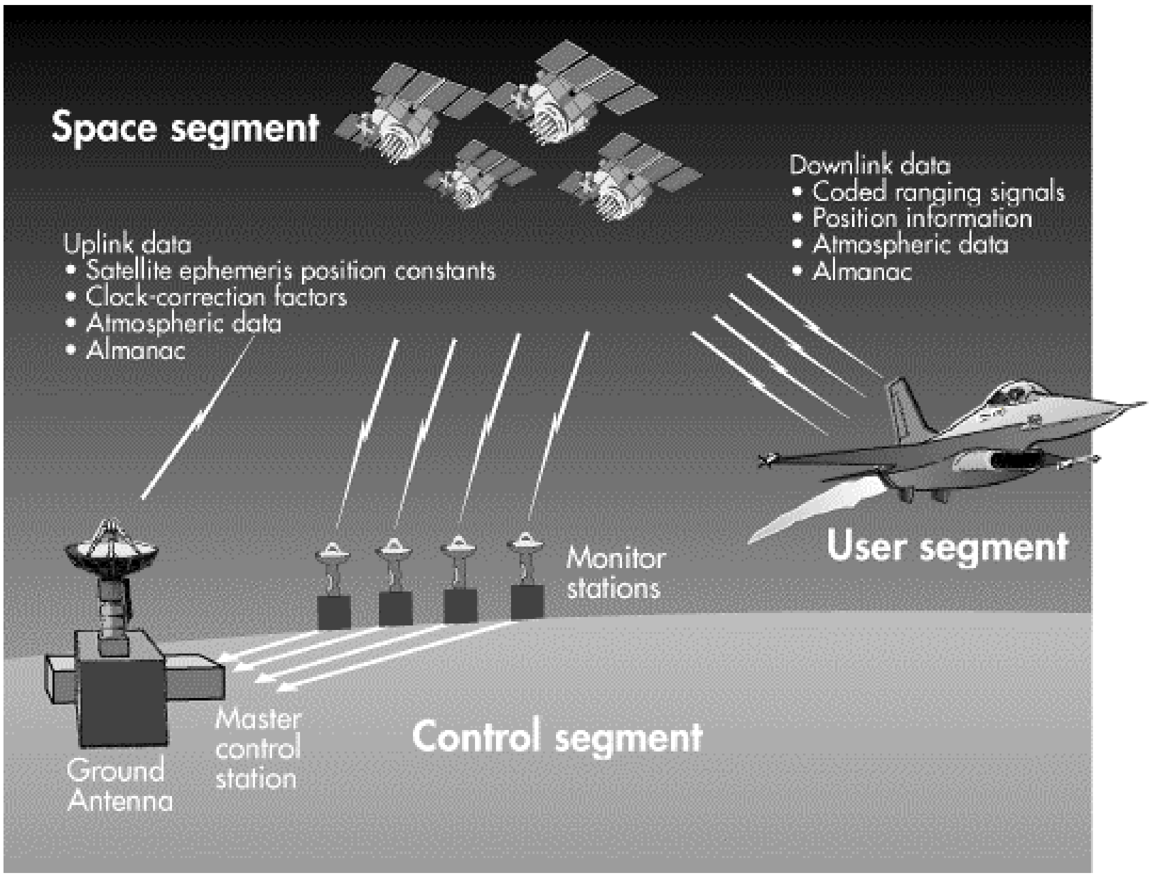


Figure 1-1, NAVSTAR Global Positioning System

Space Segment

The Space Segment consists of the orbiting GPS satellites. Its purpose is to transmit navigation signals to the User segment. The planned configuration of satellites is called the GPS Constellation; it consists of 24 satellites deployed into six different orbit planes. There are in-orbit spare satellites deployed at strategic points within the constellation. The multiplane configuration gives the system worldwide coverage capability.

The satellites move in near circular orbits with a period of 12 hours, at an approximate altitude of 10,900 nautical miles. The payload of each satellite is a special unit called the GPS Navigation Package. This package produces the navigation data that the satellites transmit on the L1 (1575.42MHz) and L2 (1227.6MHz) signals. On board the satellite there are several different timing sources. Each generation of satellite has the following timing source: Block IIA has 2 Rubidium and 2 Cesium Beam standards;

Block IIR has 2 Rubidium and 1 Cesium Beam standards; Block IIF will have 1 Rubidium and 3 Cesium Beam standards. The system uses two atomic clocks at anyone time to generate timing signal on-board the satellite and allow the users to approximate Universal Time Coordinated (UTC) time standard.

Operational Control Segment (OCS)

The purpose of this Segment is to monitor and control the GPS satellites in the Space Segment. The OCS (figure 1-1) consists of the Master Control Station (MCS), Ground Antenna (GA) sites, and the Monitor Station (MS) sites.

Master Control Station

The primary function of the MCS is to provide a command and control of the GPS constellation through operations with the MS's and GA's located around the world. MCS receives precise measuring of range from the GPS Space Vehicles (SV's), the recovery of almanac data in the transmitted signals and the measurement of the signal quality from MS's around the world. The GA's around the world provide the MCS with the ability to transmit commands and navigation uploads information to, and receives telemetry from SV's. The MCS provides operator-machine interfaces to control all the GA's and MS's. The MCS remotely control and monitors equipment status of all GA's and MS's using a TCP/IP network.

Ground Antenna

The GA Subsystem consists of equipment and computer programs necessary to transmit commands and navigation upload information to, and receive telemetry from, GPS Space Vehicles (SV's). Each GA will normally operate as an unattended, remotely controlled station. The GA Subsystem consists of four functionally identical antenna stations. All GA Subsystem operations are under control of operators at the Master Control Station (MCS). Communication Security (COMSEC) links between the MCS and each GA Subsystem site are used for transmission of GA Subsystem control and status, SV commands and upload information, and SV telemetry data. S-Band Radio Frequency (RF) is used for uplink and downlink communication between the GA Subsystem and the SV's. Each GA Subsystem has the capability to communicate with all visible GPS SV's, one at a time.

The GA sites provide a two-way communications link with the GPS satellites. Command and control of the satellites is accomplished using the S-band uplink (1783.74 MHz) and downlink (2227.5 MHz) capability of each GA. MCS personnel remotely operate each GA. Site personnel provide maintenance locally.

The Ground Antenna is an important part of the GPS control segment. Without the GA, there would be no communication with the Satellite Vehicle (SV). The purpose of the GA is to interface the control segment with the space segment. Let's look at a few reasons why we need to communicate with the SV's.

The most common interface with the GA and the SV is to perform the routine State of Health (SOH) supports. A SOH is required to check each subsystem onboard the SV. Suppose the Satellite Vehicle Officer (SVO) or the Satellite System Operators (SSO) determines an anomalous condition exists on an SV during one of these monitoring supports. The GA is used to transmit the safing procedures needed to correct the anomaly, as well as for functional verification to ensure the commands transmitted were received by the SV and are performing nominally.

As you know, the GPS mission is to provide accurate navigation data to its users. To accomplish this, the Navigation Subsystem onboard the SV must be updated on a routine basis. The SSO will transmit the navigation upload, when required, during an SV contact. The GA is needed to transmit these navigation messages to the SV.

Ground Antenna Installation. There are five GA installations in the GPS OCS.

Site	Location
ASCNG	Ascension Islands
DIEGOG	Diego Garcia
KWAJG	Kwajalein Islands
CAPEG *	Cape Canaveral
PIKEG **	Colorado Springs (Schriever AFB)

Notes:
* CAPEG is used for normal operation, it also to supports prelaunch checkout, or compatibility testing of SV's.
** PIKEG is a resource of the Air Force Satellite Control Network (AFSCN) and is known as the Colorado Tracking Station (CTS).

Each GA site is subdivided into four functional elements: Control and Status Element (CSE), RF Element (RF) (Uplink & Downlink), Antenna Element (AE), and Technical Facility Element (TFE). Each subsystem performs a specific function, allowing MCS crewmembers to carry out such tasks as configuring GA equipment, transmit commands to the SV, and monitor subsystem status. Figure 1-2 illustrates the relationship of these elements to the MCS and the SV's. The Control and Status and RF Elements contain redundant equipment and together form operational and standby equipment groups within the GA. Figure 1-3 illustrates the relationship of these to equipment group (A & B strings). The non-redundant equipment is assigned to the operational group. The following paragraphs provide a simplified functional description of each element.

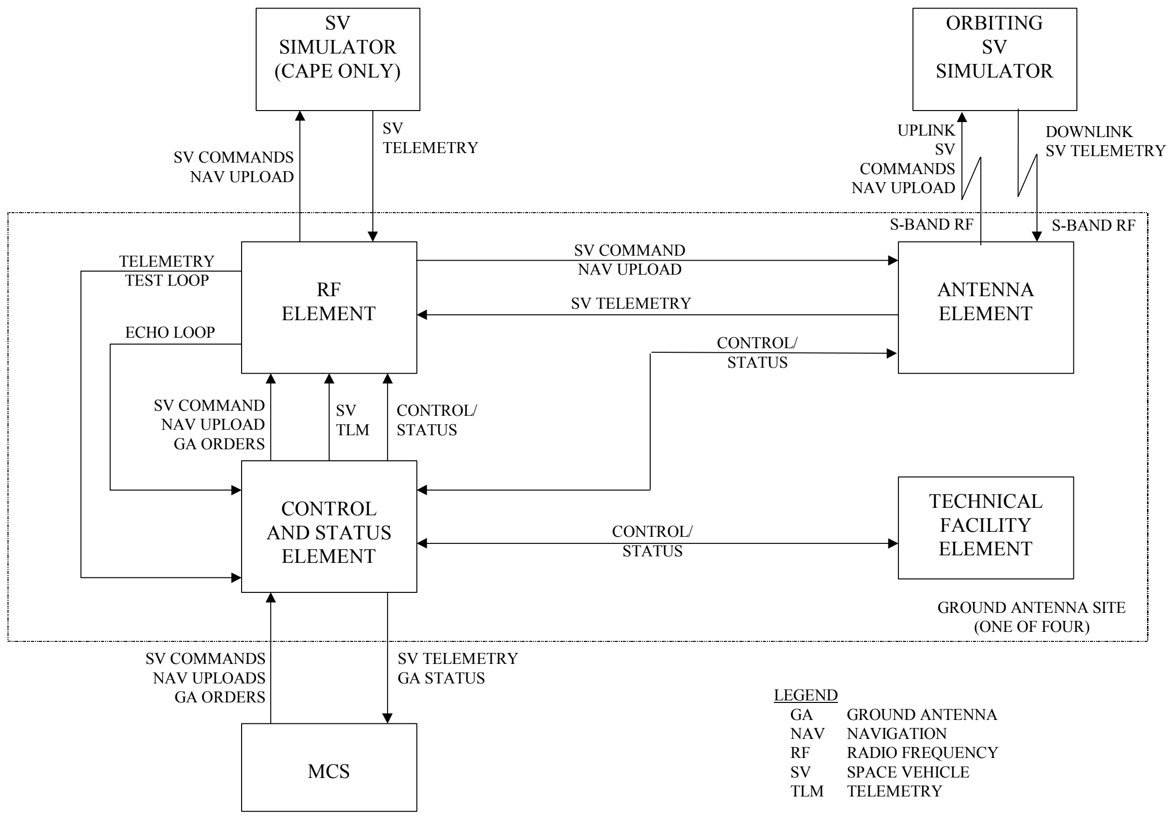


Figure 1-2. GA Elements, Block Diagram

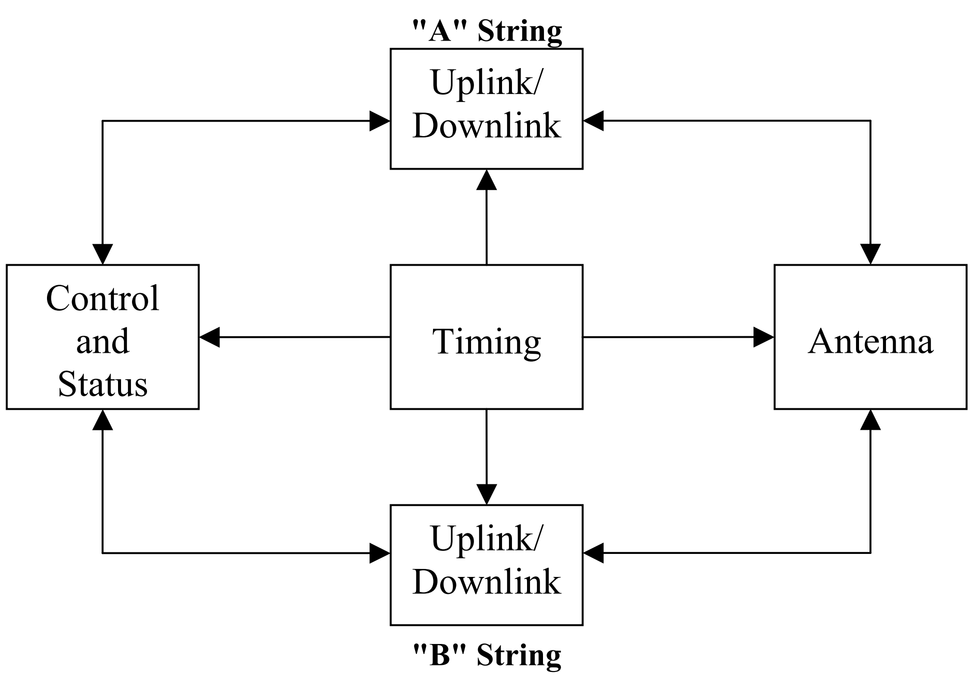


Figure 1-3 Ground Antenna Redundancy

Control and Status Subsystem Element (CSE) - The CSE performs the following functions:

a. Interfaces control and status information between each GA element and the MCS. Data transmitted from the MCS to the GA consists of SV command and navigation upload messages, tracking messages; MCS initiated orders, readiness test orders, communication and equipment test data, acknowledgments, and configuration control signals. Data transmitted to the MCS from the GA consists of SV telemetry data, GA status messages, GA recording catalog, returned stored data, test data, readiness test reports, stored message retransmission requests, and acknowledgments.
b. Accepts Uplink SV Commands and Navigation Uploads from the MCS and sends them to the RF Element for transmission to the SV.
c. Receives and processes Downlink SV Telemetry from the RF Element and transfers this information to the MCS.
d. Accepts Telemetry Test Loop information from the RF Element and transmits this information to the MCS to verify downlink operation.
e. Accepts Echo Loop information from the RF Element and transmits this information to the MCS to verify uplink operation.
f. Provides local control capability to support maintenance functions.

RF Element - The RF Element performs the following uplink, downlink, and test functions:

a. Accepts digital Uplink SV Commands and Navigational Upload Data from the Control and Status Element, Frequency Shift Keys (FSK) the data, phase-modulates the FSK data onto an S-Band carrier, and amplifies the S-Band RF for output to the Antenna Element.
b. Accepts downlink S-band RF from the Antenna Element, phase-demodulates data from the carrier, performs bit synchronization, and provides digital serial telemetry output to the Control and Status Element.
c. Provides an echo loop output to the Control and Status Element. The RF Element provides circuits to sample uplink S-band RF output, phase-demodulate the FSK data from the carrier, and decode FSK data to provide a digital output to the Control and Status Element for uplink operation verification.
d. Simulates telemetry test data and phase-modulates a test message onto the RF carrier applied to the downlink equipment. The downlink equipment functionally applies a digital telemetry test loop signal to the Control and Status Element for testing downlink operation.
e. Accepts control and outputs status for interface with the Control and Status Element. RF Element equipment control and status consists of coaxial and waveguide switch control and status, equipment configuration control signals such as bit rates and power level selection, and downlink equipment lock status.

Antenna Element (AE) - The AE provides S-band RF uplink and downlink signal paths between the GA and one SV. The Antenna Element performs the following functions:

a. Accepts an uplink S-band RF signal containing SV commands and navigation upload data from the RF Element and radiates the signal for transmission to an SV.

b. Accepts a downlink S-band RF signal containing telemetry data from an SV, amplifies the signal, and outputs the data to the RF Element.
c. Accepts control and outputs status for interface with the Control and Status Element. Antenna elevation and azimuth positions are controlled by MCS commands applied through the Control and Status Element. Status signals contain information to indicate azimuth and elevation position and operational status.
d. Provides capability for manual control of antenna operation and position. Manual control is used for maintenance functions.

Technical Facility Element (TFE) - The Technical Facility Element provides equipment and structures necessary for GA operation. These include power distribution equipment (including Emergency Power Off (EPO) circuitry), Radome, environmental control, equipment shelters, lighting, smoke and intrusion alarms, and similar type equipment. Control and status interface with the Control and Status Element is supplied where applicable.

The following paragraphs discuss functional design of the GA. The information demonstrates how the four elements interact during normal operations.

MCS/GA COMMUNICATION CIRCUIT FUNCTIONAL

MCS/GA Communication circuits support the data communication between the MCS and the GA by using two full-duplex (three at the CAPE) serial links with a data rate of 19.2 kbps each. The communication path includes Defense Information Switching Network (DISN) communications equipment, Red Shelter Local Area Network (LAN) equipment and the redundant workstations. This link is designed so that no single communications link or active equipment failure will cause a loss of data communications between the MCS and the GA. Additionally, the MCS/GA communication equipment utilizes active load sharing in the 2509 routers to maximize use of available bandwidth. Encrypted Data is received at the Digital Service Unit (DSU) from the site communication center. Clock and data signals are transferred from the DSU to the KG-84 where the data is decrypted and forwarded to the 2509 router. The routers convert the decrypted (Red) serial data to Ethernet and then transfer the information to the GA workstation via the Red Shelter LAN. Figure 1-4 shows a simplified interconnection of the MCS/GA Communication Circuit.

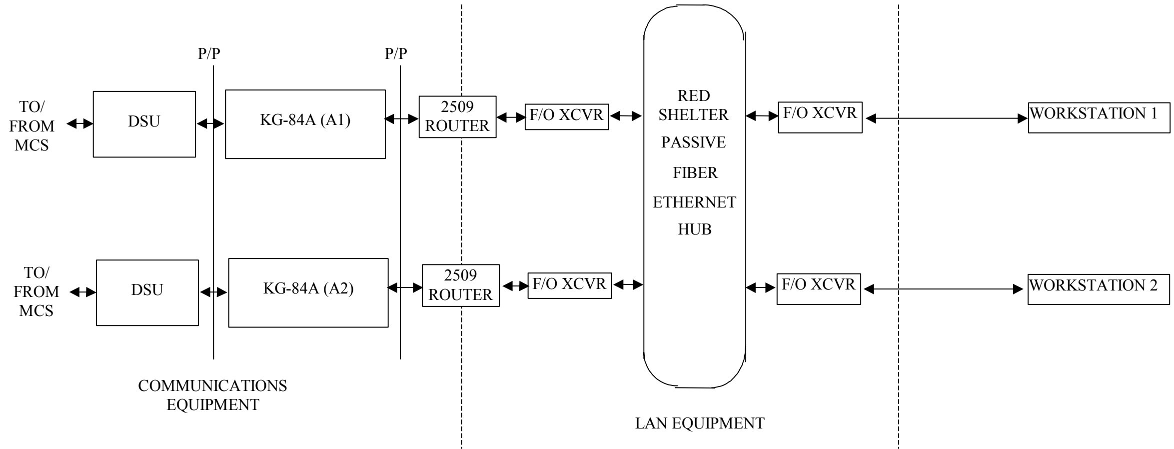


Figure 1-4. MCS/GA Communication Circuit, Simplified Block Diagram

RED AND BLACK LOCAL AREA NETWORK (LAN) FUNCTIONAL

The Local Area Network consists of a Red Shelter Passive Fiber Ethernet Hub, a Black Shelter Passive Fiber Ethernet Hub, a Cisco 2514 router, a Red/Black Shelter Fiber Optic Interface, three Media Converters, and Fiber Optic Transceivers (F/O XCVR) connected to the individual equipment on the network. These LAN connections provide connectivity for all Red Shelter and Black Shelter equipment to the GA workstation and MCS/GA Communication circuits. The Red Shelter LAN is isolated from the Black Shelter LAN by the Red/Black Shelter Fiber Optic Interface and a Cisco 2514 router that blocks all non-Black Shelter LAN data packets from the Black Shelter Ethernet. Figure 1-5 shows a simplified interconnection of the LAN equipment.

GA WORKSTATION (W/S) EQUIPMENT FUNCTIONAL

The workstation receives stores and processes messages from the MCS. When a track order is sent from the MCS to the GA workstation, it configures the GA equipment for operations. Once the GA is configured the MCS will instruct it to start sending transmitting data via GA uplink equipment to the Satellite (Called Navigational Uploads). The Work Stations also receive data and status from the GA equipment. The data is processed and forwarded to the MCS. The Workstation can be considered the brains of the GA.

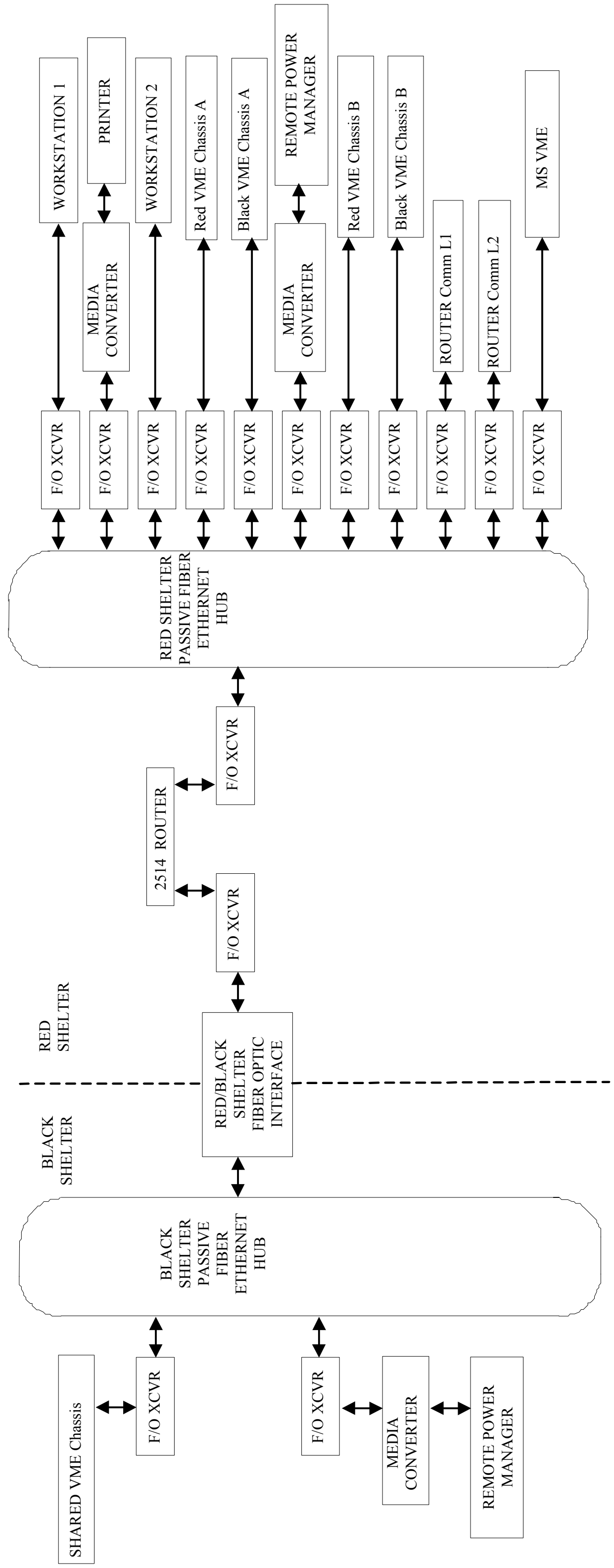


Figure 1-5. Red and Black Local Area Network (LAN), Simplified Block Diagram

RED/BLACK SHELTER FIBER OPTIC INTERFACE FUNCTIONAL

The purpose of the Red/Black Shelter Fiber Optic (F/O) Interface is to provide connectivity between the Red Shelter and Black Shelter facilities and their respective GA equipment. The interface performs copper-to-fiber and fiber-to-copper conversion for data transferred between the Red and Black equipment shelters. In addition, the Red/Black Shelter Fiber Optic Interface provides TEMPEST signal isolation for the signals routed between the Red and Black Shelters. The Red/Black Shelter F/O Interface consists of an Optelecom F/O Communication chassis, a Siecor F/O Distribution and patch panel, and a 24 strand, multimode, fiber optic cable. There are two identical F/O Communication Systems located within the GA. One system is dedicated to the A String equipment and the Black Shelter Ethernet LAN, the second system is dedicated to the B String equipment and does not have a connection to the Black Shelter Ethernet LAN. In the Red Shelter a single F/O Distribution and patch panel provides the fiber optic connections for both the A and B strings equipment. See Figure 1-6 for a simplified block diagram showing interconnection of the Red/Black Shelter F/O Interface equipment.

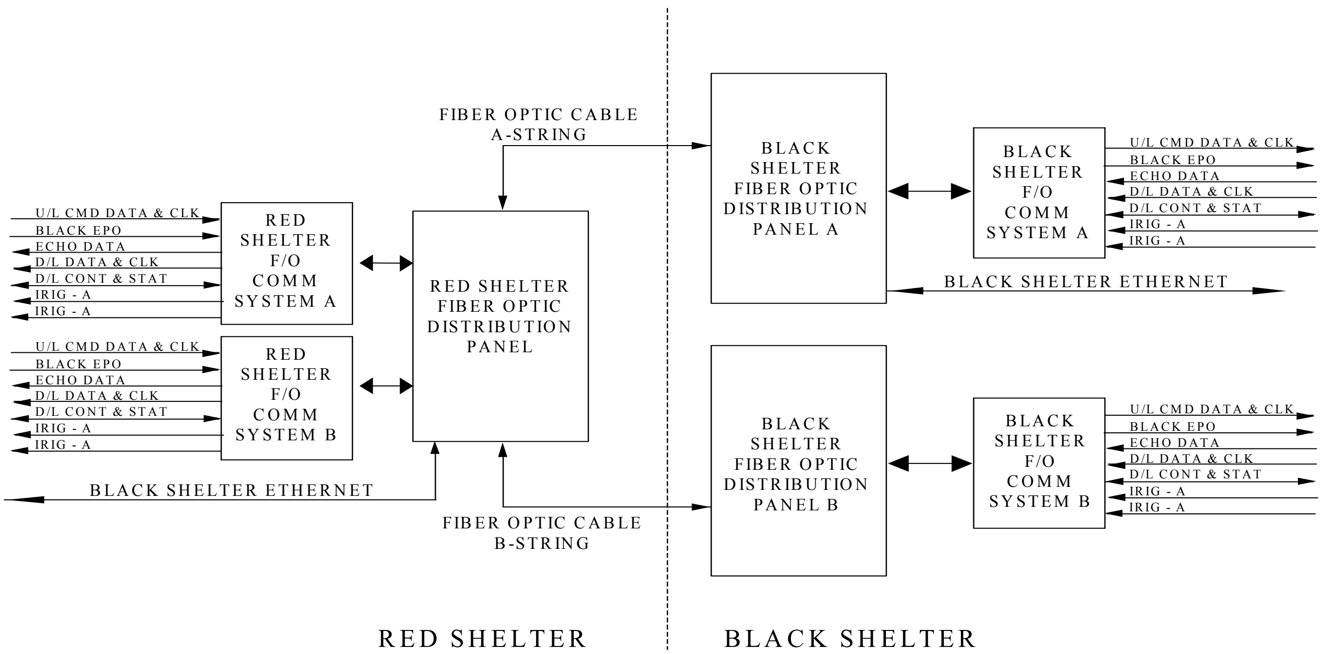


Figure 1-6. Red/Black Shelter Fiber Optic Interface, Simplified Block Diagram

Uplink Subsystem

The uplink circuits process SV commands and navigation upload data, modulate the data onto an S-Band RF carrier, amplify the RF signal and radiate the uplink signal to the SV. Uplink data consists of digital messages containing commands and navigational upload data for the SV. Uplink data is sent from the MCS to the GA Workstation via the MCS Link Equipment. Once the uplink data message is received by the GA Workstation it is sent to either the Red VME or Black VME in response to orders generated at the MCS. When the uplink data is clear, the message length can vary from 16 to 62 or from 64 to 65535 bits. When uplink data is encrypted, uplink commands are 63 bits long. All other bit combinations are invalid. With the exception of the Antenna, and related waveguide switching, the two equipment strings (A and B) providing identical signal paths. During normal operation of the GA, one string will be selected as operational and the other as standby. See Figure 1-7 for a simplified block diagram of a single uplink data circuit.

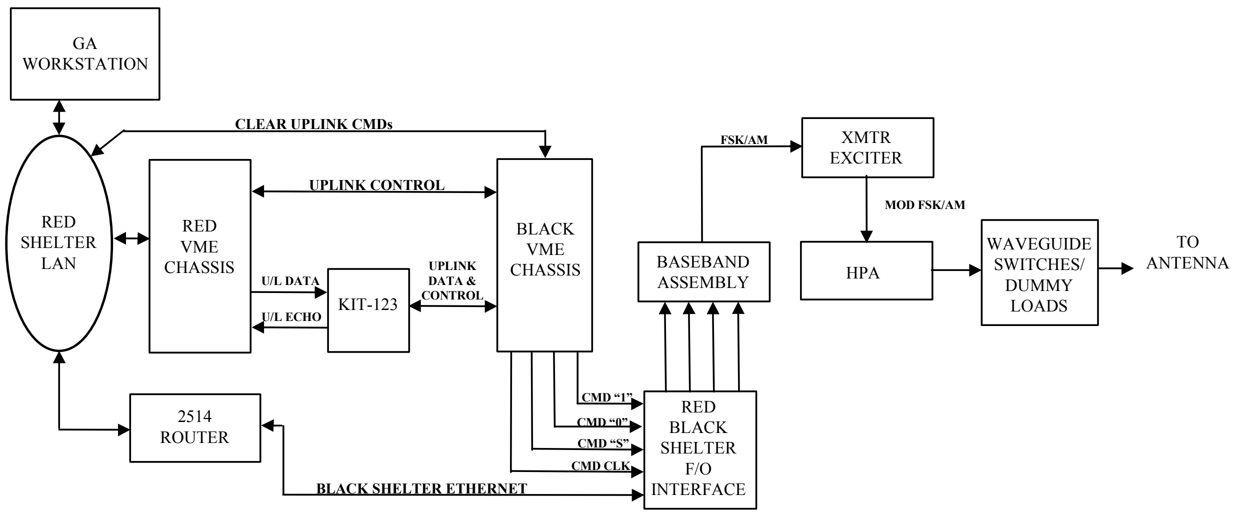


Figure 1-7. Uplink Data Circuit, Simplified Block Diagram

Clear Uplink Data Circuit Functional Description. When the uplink data message is to be clear, data is routed from the GA workstation to the Red Shelter LAN. Clear uplink requests are received at the Black VME Uplink CPU and formatted by the Ternary I/O module into a ternary 1, 0, S format required by the Baseband Assembly. The ternary data signals are transferred through the Red/Black Shelter F/O Interface to the Baseband Assembly in the Black Shelter uplink equipment group. The Baseband Assembly receives the ternary data from the Black VME, frequency shift keys (FSK) the three signals (1= 95 KHz, 0 = 76 KHz and S = 65KHz) and amplitude modulates (AM) the FSK signal with a 500 Hz triangular waveform. The FSK/AM output is then applied to the Transmitter-Exciter. The Transmitter-Exciter phase-modulates the FSK/AM data onto a 1783.74 MHz carrier and outputs the S-Band RF signal to the HPA. The Transmitter-Exciter also controls the uplink power level. The HPA amplifies the S-Band RF input between 100 to 102.5 dB and sends the outputs to the antenna via waveguide switches. Two waveguide switches are used to switch the HPA output to the Antenna or a dummy load (when not transmitting to SV). The Antenna radiates the S-Band RF uplink data signal to the SV.

Encrypted Uplink Data Circuit Functional Description. When the uplink data is to be encrypted, data is routed from the GA Workstation to the Red Shelter LAN. Encrypted uplink requests are received at the Red VME and transferred to the KIT-123 for encryption, then routed to the Black VME. A 5-kHz clock signal, Uplink Control, is generated in the Red VME and controls encrypted data transfer via a Fiber Optic Isolator. After data is encrypted, the Black VME formats the data into a ternary 1, 0, S format required by the Baseband Assembly. At this point the encrypted uplink data path is routed the same as the clear uplink data path.

Uplink Control and Status Circuit Functional Description. Uplink control and status circuits provide an interface with the appropriate GA Workstation to control and monitor the uplink data equipment. Two control and status channels (A and B) provide identical signal paths between the GA

Workstation and its dedicated uplink equipment. All control messages required for uplink data handling are supplied by the Operational GA Workstation, and all uplink equipment status messages are received by the Operational GA Workstation for transmission to the MCS. The Red Shelter LAN is used to interface uplink control and status signals between the GA Workstation and the Red and Black VME chassis. Uplink data transfer between the Red VME and Black VME is controlled by three control signals: MESSAGE GATE, KIT ERROR, and KIT RESET. These control signals are routed through the Red/Black Isolator on the rear of the Red VME. Control signals to and status signals from the KIT-123 equipment are routed through the Black VME via the Red Shelter LAN. The Black VME uses control and status signals with the KIT-123 to transfer data between the Red VME and the KIT-123 equipment. The Black VME also uses control signals for the initialization of the KIT-123 and receives alarm and power-on status signals from the KIT-123. The GA Workstation uses the Red Shelter LAN, 2514 router, Red/Black F/O Interface, Black Shelter LAN, and Shared VME for the control and status interface with the Black Shelter uplink equipment. The Shared VME controls and monitors both the A and B string Transmitter-Exciters and Power Meters, the Data Acquisition and Control Unit (DACU), and the Servo Control Unit (SCU) through a parallel GPIB interface. Control to the Antenna waveguide switches and status from the HPA and Antenna waveguide switches are supplied by the DACU through the Shared VME GPIB interface. See Figure 1-8 for a simplified block diagram showing the interconnection of the uplink control and status equipment.

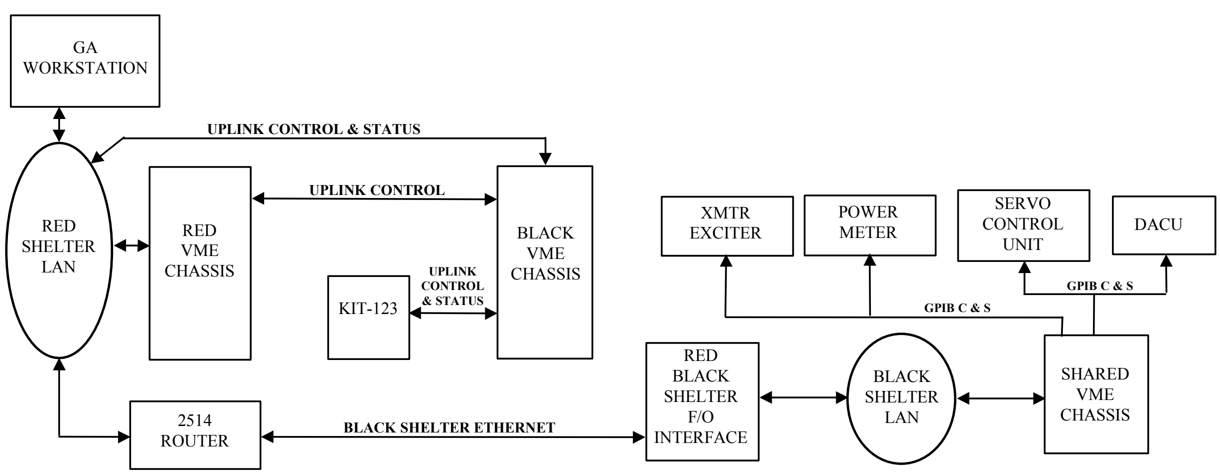


Figure 1-8. Uplink Control and Status Circuit, Simplified Block Diagram

Echo Loop Circuit Functional Description. The Echo Loop samples the RF uplink signal and demodulates the command and navigational upload data from the signal. The decoded data is returned to the Black VME for verification of the transmitted uplink data. An RF sample port in each of the HPAs provides sampled uplink RF to an Echo Coupler. The Echo Coupler couples the signal through an attenuator to the Echo Switch. The Echo Switch allows the RF uplink sample from either HPA-A or HPA-B to be switched to the Echo Receiver. The off-line RF sample is terminated in a dummy load. The Echo Receiver demodulates the S-Band phase–modulated RF sample to extract the Frequency Shift Key (FSK)/Amplitude Modulated (AM) data. This demodulated FSK/AM data signal is then routed through an attenuator to the Command Decoder. The Command Decoder receives the FSK/AM signal and extracts the ternary data (1, 0, S). The ternary data is sent to each Black VME via the Red/Black F/O Interface. The Black VME receives the ternary echo data at the Ternary I/O module and performs a data bit comparison with the transmitted command. The Black VME echo status is sent to the GA Workstation via the Red Shelter LAN. See Figure 1-9 for a simplified block diagram showing the interconnection of the echo loop equipment.

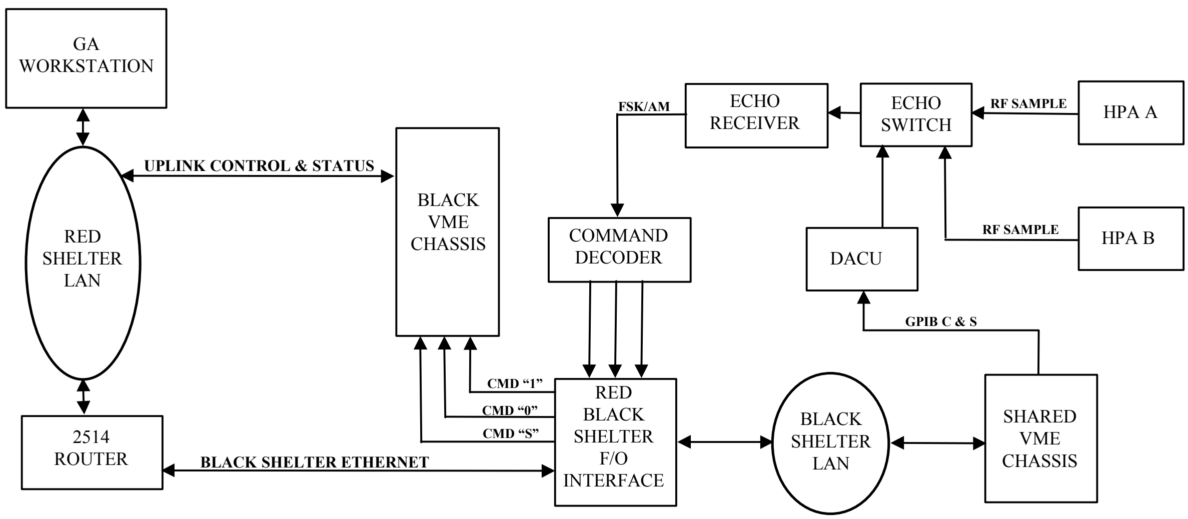


Figure 1-9. Echo Loop Circuit, Simplified Block Diagram

Downlink Subsystem

The purpose of the Downlink circuit is to receive and process downlink data from the SV. Downlink circuits receive the RF S-Band signal and route it through the Antenna, the Black Shelter RF equipment, the Red/Black Shelter F/O Interface, the Black VME, and the decryptors to the Red VME for decommutation.

<u>Downlink Data Circuit Functional Description</u>. The Downlink data is processed through the RF downlink equipment and forwarded to the GA Workstation for transmission to the MCS. With the exception of the Antenna, Receive Switch, and Couplers, two equipment strings (A and B) are supplied to provide identical signal paths. During normal operation of the GA, one channel will be selected as operational and the other as standby. The RF downlink signal from the SV is received by the Antenna equipment and fed to the Receive Switch and Couplers. The Receive Switch and Couplers switch and couple the downlink RF signal (2227.5 MHz) to either the A String or B String Telemetry Receiver. The Telemetry Receiver phase-demodulates the RF signal to provide a 1.7 MHz subcarrier modulated with Biphase-Shift Key (BPSK) data to the Phase Shift Key (PSK) Modem. The PSK Modem demodulates the subcarrier to provide the data signal to the Bit Synchronizer. The Bit Synchronizer provides synchronized Transistor-Transistor Logic (TTL) data and clock signals to the Red/Black Shelter F/O Interface for transfer to the Red Shelter equipment. The Red/Black Shelter F/O Interface outputs the synchronized TTL data and clock to the Black VME. The data is transferred from the Black VME to the Red VME through one of two KGR-28 units used to decrypt the telemetry data. The output of the KGR-28 decryption unit is routed to the Red VME for decommutation. The Pulse Code Modulation (PCM) Decommutator frame synchronizes converts it from serial to parallel, and time tags the data before transferring the data to the GA Workstation via the Red Shelter LAN. The downlink data is received by both GA Workstations and the operational GA Workstation forwards the data for processing by the MCS. See Figure 1-10 for a simplified block diagram showing the interconnection of the downlink data equipment.

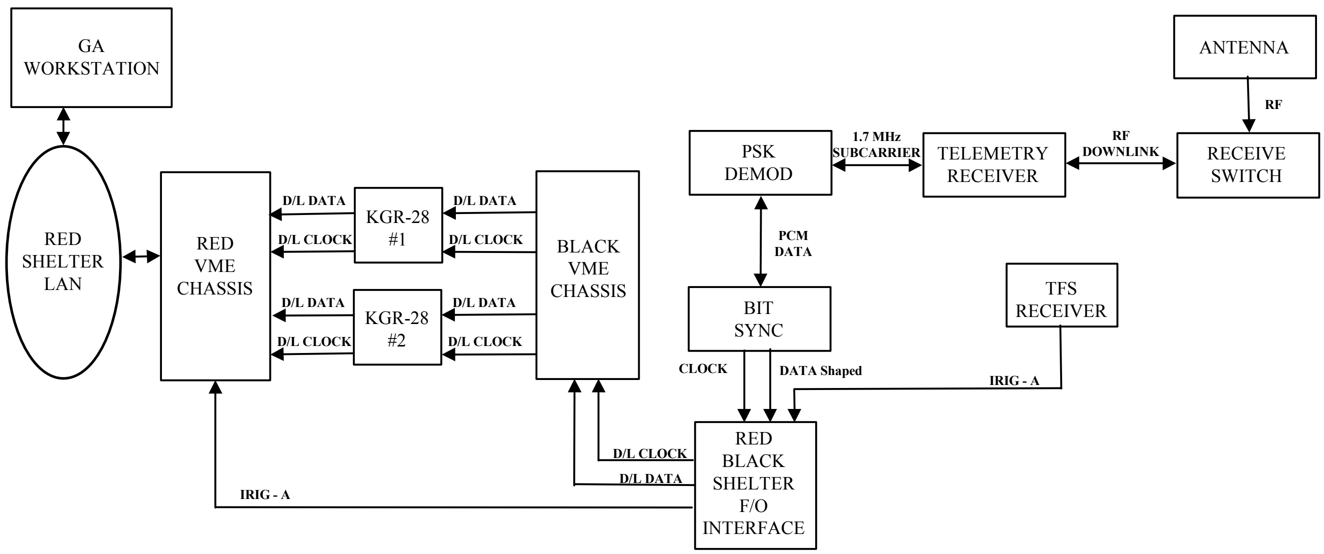


Figure 1-10. Downlink Data Circuit, Simplified Block Diagram

Downlink Control and Status Circuit Functional Description. Downlink control and status circuits provide an interface to the Black VME Chassis to control and monitor status of the Black Shelter downlink data circuit. Two control and status strings (A and B) are supplied to provide identical signal paths. All control and status messages required for downlink data processing interface with the operational GA Workstation. Decommutator control and status information is transferred between the GA workstation and the Decommutator via the Red Shelter LAN. The Black VME sends downlink address control signals to the KGR-28A decryption units and receives address selection and ready status from the decryption unit. The GA Workstation communicates, over the Red Shelter LAN, with the Black VME to transfer control and status information to downlink equipment in the Black Shelter. The PSK Demod and Bit Synchronizer control and status interfaces with the Black VME via the Red/Black Shelter F/O Interface. The Black VME communicates the control to and receives the status information from the PSK Demod and Bit Synchronizer over discrete output lines. There is no Telemetry Receiver control from the Black VME and the Lock status is surmised from the sync Lock output of the PSK Demod. The Receiver Lock status is also sent to the Black VME via the Red/Black Shelter F/O Interface. The Receive Switch performs selection of the downlink string (A or B) to be used for data processing. The switch is controlled by the DACU, which receives configuration information from the Shared VME GPIB interface. The Shared VME receives control from and provides status data to the GA Workstation via the Black Shelter LAN, Red/Black Shelter F/O Interface, 2514 router and the Red Shelter LAN. See Figure 1-11 for a simplified block diagram showing the interconnection of the Downlink Control and Status Equipment.

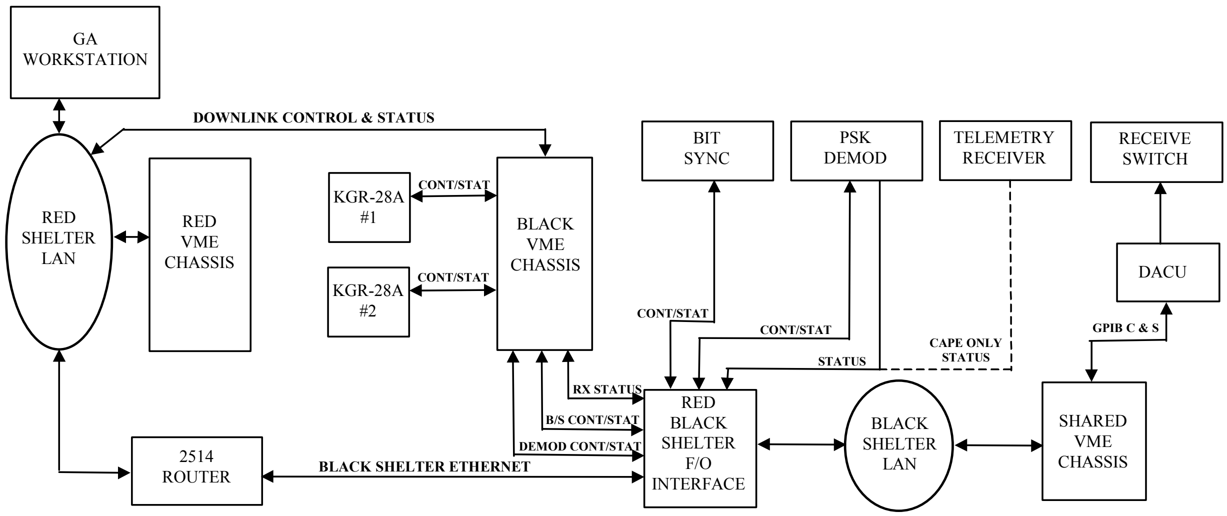


Figure 1-11. Downlink Control and Status Circuit, Simplified Block Diagram

Test Loop Circuit Functional Description. The Telemetry Test Loop simulates a downlink test signal, phase modulates the test data onto the downlink RF carrier, and applies the signal to the downlink equipment to verify proper operation. The GA Workstation provides the control and status interface for the PCM Simulator via the Red Shelter LAN, 2514 router, Red/Black Shelter F/O Interface, Black Shelter LAN, and the Shared VME. Upon receiving a control message via the RS-232 interface from the Shared VME, the PCM simulator generates a pre-selected PCM pattern and sends the selected data pattern to the B String PSK Modem. The modulation section of the B string PSK Demodulator biphase-shift key modulates the data with a 1.7 MHz subcarrier and outputs the signal to the Telemetry Generator. The Telemetry Generator generates the GPS downlink frequency (2227.5 MHz) and phase modulates the carrier with the subcarrier and data provided by the PSK Modem. The amplitude of the Telemetry Generator output is controlled by the Shared VME via the GPIB interface. The Telemetry Generator output is applied to the Simulator Coupler. The coupled port of the Simulator Coupler delivers a sampled portion of the test signal to the Telemetry Power Meter. The Telemetry Power Meter measures the output power level of the Telemetry Generator and provides this status to the Shared VME via a GPIB interface. The through port supplies the signal to a Power Divider, which splits the signal into two paths. One path provides signal input through either the Sum or Delta Low Noise Amplifier (LNA) test loop to the on-line Telemetry Receiver. From the Power Divider, the RF signal is reduced by an attenuator and applied to another Power Divider. This Power Divider splits the RF signal into two paths for input to the Sum and/or Delta LNA test loops. Sum and Delta LNA switches allow the RF signal to be applied to the respective test loops or to dummy loads. In the Sum LNA test loop, the RF test signal from the Sum LNA switch is applied to the Sum test coupler located in the Antenna. This couples the RF test signal with the downlink SUM channel input from the Antenna. This signal is applied to the normal receive path. In the Delta LNA test loop, the RF test signal from the Delta LNA switch is sent to the Delta test coupler in the Antenna. This signal is applied to the normal receive path. See Figure 1-12 for a simplified block diagram showing the interconnection of the test loop equipment.

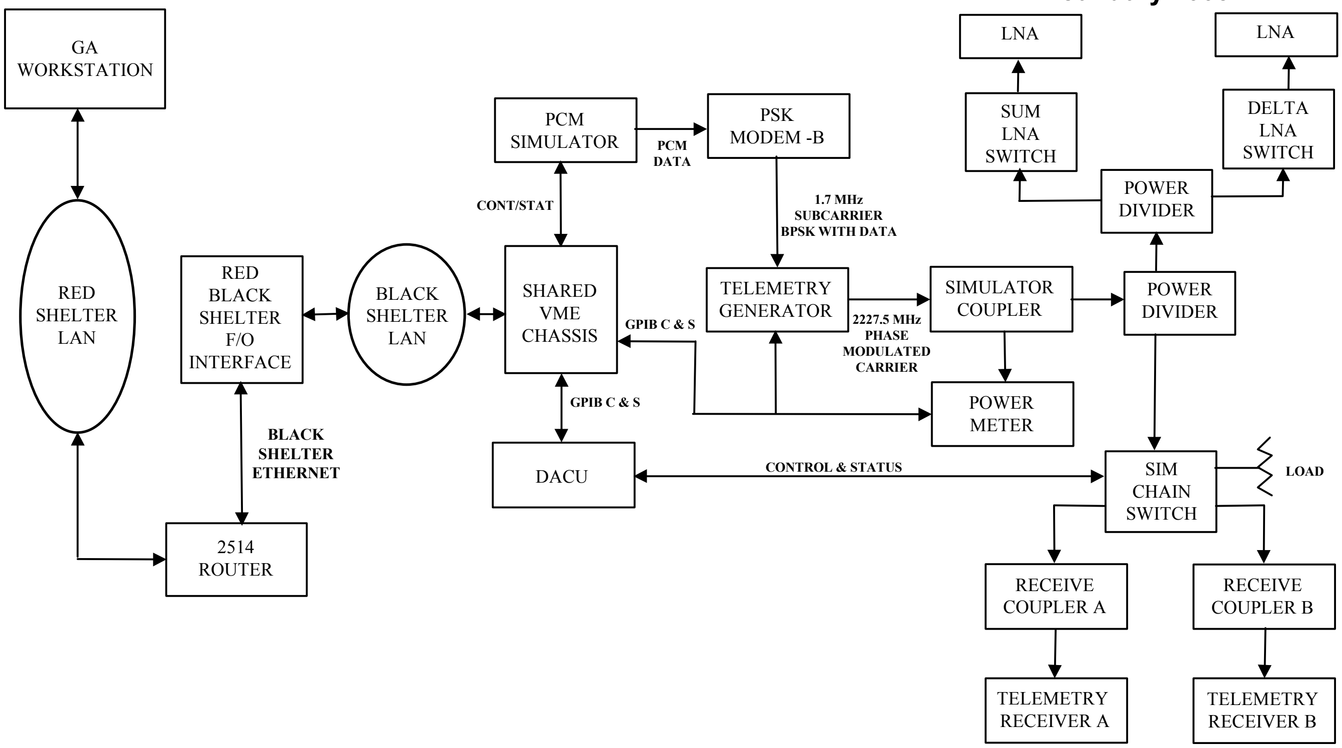


Figure 1-12. Test Loop Circuit, Simplified Block Diagram

TIMING CIRCUIT FUNCTIONAL DESCRIPTION

The Timing circuits generate the reference timing signals used by the GA equipment. The TFS Antenna receives GPS satellite transmitted time signals and supplies the signal to the TFS Receiver. The TFS Receiver receives the satellite transmitted time data and outputs an Inter-Range Instrument Group (IRIG-A) time code and a filtered 5 MHz sine wave. The IRIG-A time code signal is split (A String and B String) and routed from the TFS Receiver to the Red/Black Shelter F/O Interface where the IRIG-A signal is separated again, into two signals. The IRIG-A signal is transferred to the Red Shelter over the Red/Black Shelter F/O Interface and routed to the Red VME for use by the PCM Decommutator and to the GA Workstation for time critical command synchronization. The Decommutator uses the timing information to time-tag downlink telemetry messages from the SV. The TFS Receiver outputs a 5 MHz sine wave, which is sent to the Distribution Amplifier. The Distribution Amplifier outputs six 5 MHz reference (REF) signals that are individually adjustable in amplitude. These 5 MHz REF signals are distributed to both A and B string Transmitter-Exciters, both A and B string Telemetry Receivers, the Echo Receiver and the Telemetry Generator. See Figure 1-13 for a simplified block diagram showing the interconnection of the timing circuit. The Ternary I/O module in the Black VME generates a 1 kHz Uplink clock for use by the Uplink data circuits. The Uplink clock is routed from the Black VME to the Baseband via the Red/Black Shelter Fiber Optic Interface.

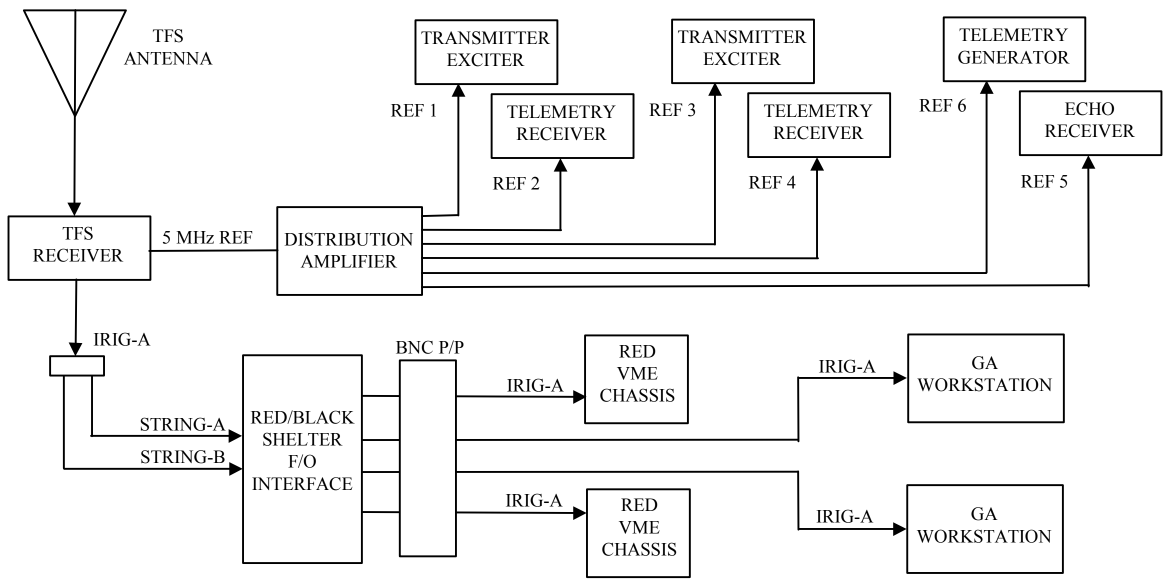


Figure 1-13. Timing Circuit, Simplified Block Diagram

Antenna Subsystem

ANTENNA CONTROL AND STATUS CIRCUIT FUNCTIONAL DESCRIPTION.

Control of Antenna positioning and status reporting is accomplished through the Servo Control Unit (SCU). Antenna position may be controlled manually, under control of the GA Workstation (Program Track), or Autotrack using the DOWNLINK RF signal. Manual control is also available from either the front panel of the SCU or from a local control unit at the base extension of the Antenna. Under normal operation, the GA Workstation will control azimuth and elevation positions. Functionally in the autotrack mode the interconnection can be separated into four groups: GA Workstation to SCU interface, autotrack loop, azimuth/elevation axis positioning, and RF Blanking. Under normal operation, the Antenna circuits are controlled and monitored by the GA Workstation. This control and monitoring is accomplished by a GPIB interface between the Shared VME and the SCU.

Antenna Control and Status, Autotrack Circuit Functional Description. In the autotrack loop configuration the SCU, Monoscan Converter, Telemetry Receivers and Delta Error Horns function as a loop to enable the autotrack function of the Antenna. The four Delta Error Horns are used (two for azimuth and two for elevation) to receive the DOWNLINK RF signal. These signals are applied to a Monopulse Comparator to detect any phase differences, which will occur if the Antenna is not pointing directly at the SV generating the DOWNLINK RF. The Delta AZ and EL signals are applied to the Monoscan Converter, which uses the timing inputs from the SCU to output a scan-modulated DELTA RF signal. The DELTA RF signal is amplified by the DELTA LNA and coupled onto the DOWNLINK RF signal received by the Sum Horn in the DOWNLINK RF Channel Coupler. The DOWNLINK RF is routed through the receive switch and applied to either Telemetry Receiver-A or Telemetry Receiver-B equipment. The AM detector in the Telemetry Receivers provides AM TRACKING VIDEO to the SCU and the PM Demodulator provides AGC to the SCU. When in the autotrack mode, the SCU processes AM video signals from the selected receiver and convert these into error signals. These error signals are provided to the servo control loops used by the azimuth and elevation drives to track the DOWNLINK RF signal.

Antenna Control and Status, Position Circuit Functional Description. In the azimuth/elevation axis positioning configuration, the drive motors in the azimuth and elevation axes are controlled by the SCU. Status indications of limit switch positions, tachometer readings, alarms, etc. are supplied to the SCU. When enabled by the SCU, the local control unit can also be used to slew the Antenna position. In the RF Blanking configuration, the Antenna contains sector blanking switches which prevent RF radiation between predetermined azimuth points when the antenna elevation is below a set limit. Also, the Antenna is provided with a TRANSMIT DISABLE switch to turn Beam Power off to the HPAs. See Figure 1-14 for a simplified block diagram of the Antenna Control and Status Circuit.

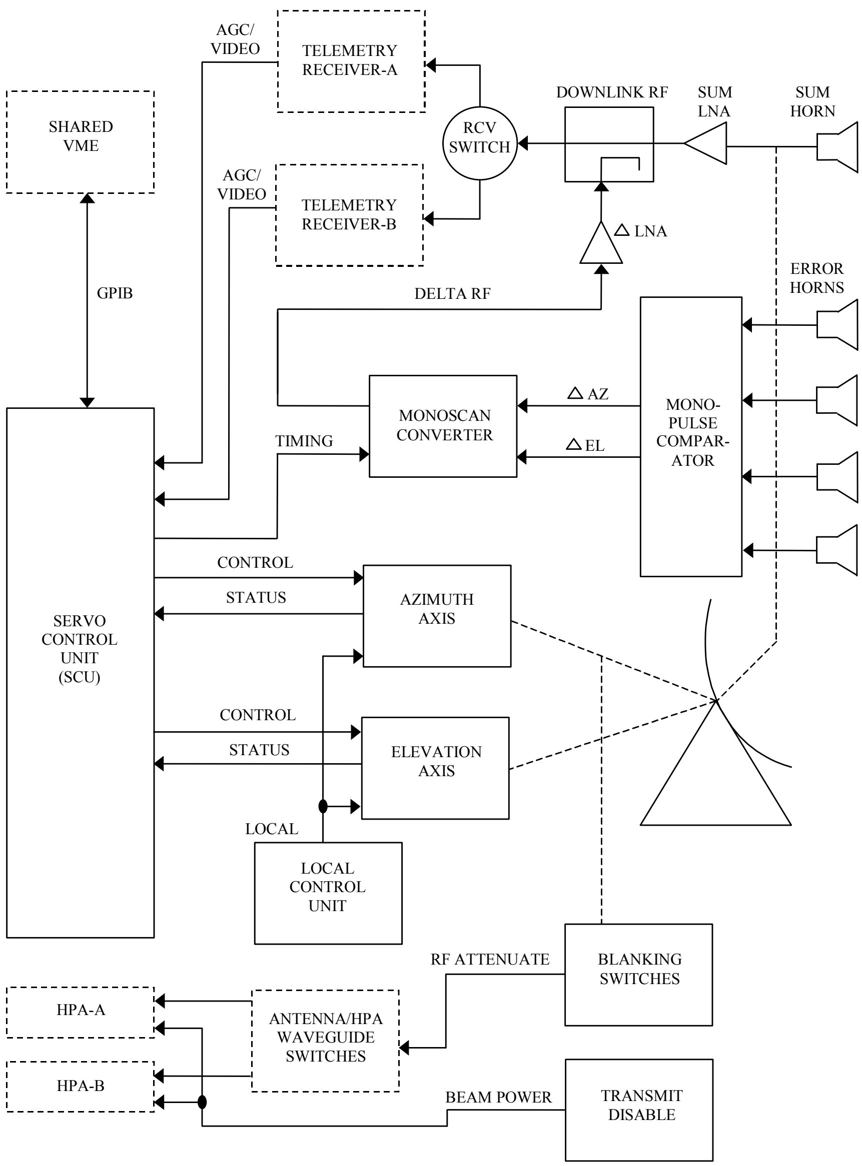


Figure 1-14. Antenna Control and Status Circuit, Simplified Block Diagram

Monitor Station

The MS consists of equipment and computer programs to monitor the L-band navigational signals transmitted from the GPS Space Vehicles (SV's). Monitoring involves the precise measuring of range from the SV, the recovery of almanac data in the transmitted signals and the measurement of the signal quality. This data is packaged and transmitted to the Master Control Station (MCS) for processing via the communications network. Additional information on the status of MS equipment is also packaged and transmitted to the MCS.

The MS extracts pseudo random noise (PRN) codes, and obtain from those codes the range to the SV - called pseudorange (PR). The MS is responsible for gathering the measurements necessary to ensure users are provided with accurate navigation data. Without the MS, the GPS mission could not be carried out.

Pseudorandom Noise Codes - The MS receives two pseudorandom noise (PRN) codes from the SV. These codes are called precision (P) code and course/acquisition (C/A) code. The P code is a pseudorandom binary sequence transmitted at 10.23 Million bits per second (Mbps). The code could run thirty-eight weeks before ever repeating; however, it is reset after one week for each SV. Each SV transmits a different portion of the code; this allows the monitor station to distinguish between each SV.

The C/A code is similar to the P code except that it is less accurate. The C/A code consists of 1023 bits of binary data at a bit rate of 1.024 Mbps. Thus, the C/A codes repeat every millisecond. The C/A code is kept 3dB to 6dB stronger than the P code, so it is relatively easy to receive.

These codes are transmitted on two frequencies referred to as L1 and L2. L1 has a frequency of 1575.42 MHz and transmits both P code and C/A code. L2 transmits at 1227.6 MHz and transmits either the P or C/A code.

The reason for using two frequencies is to correct for the depth of the ionosphere. When a radio signal passes through the ionosphere the signal is bent. The lower the frequency, the slower it passes through the ionosphere (Figure 1-15). By comparing the difference between the two signals, the depth of the ionosphere can be determined and PRs can be calculated with greater accuracy.

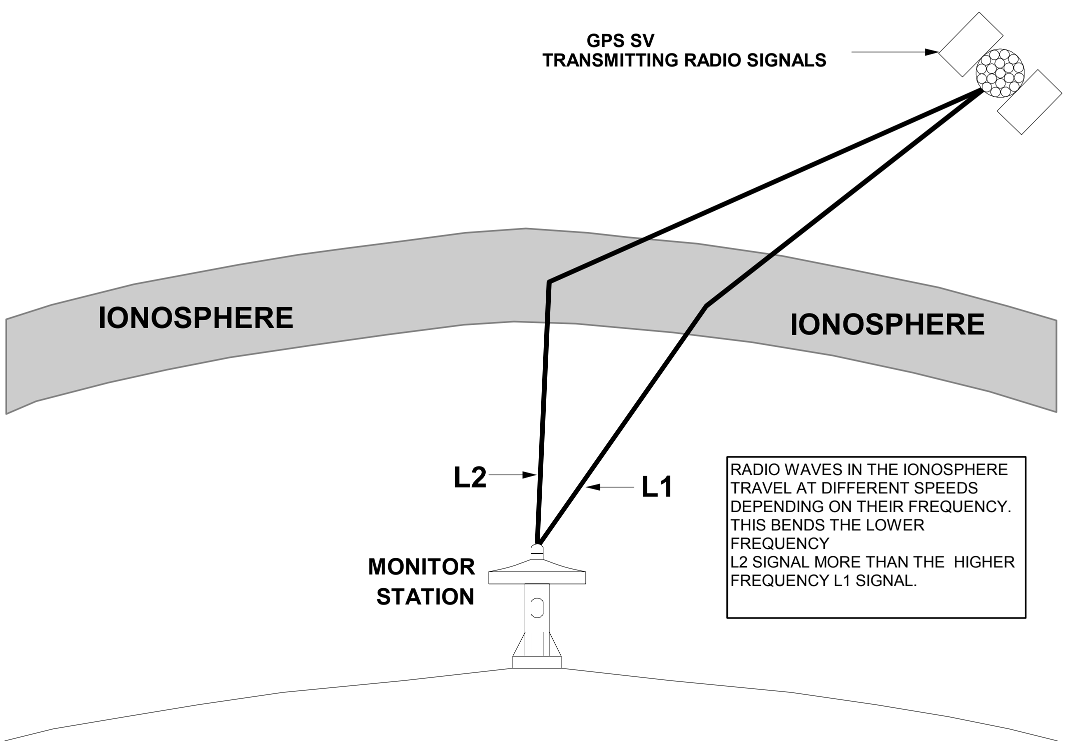


Figure 1-15. Ionospheric Effects on L-band Signals

Pseudorange Measurement - The SV transmits both P and C/A code. The monitor station compares the received code with a reference code. The difference between the received code and the reference code represents the range to the SV.

The GPS MS sites around the world continuously monitor navigation signals from SV's in the GPS constellation. Information on the signal quality, data content, and accuracy of navigation signals is transmitted to the MCS for the Global Positioning System.

Monitor Station Installation. There are six MS installations in the GPS OCS.

Location	Mnemonic Name	Collocated Equipment
Ascension Island	ASCN	collocated with Ground Antenna (GA)
Diego Garcia	DIEGO	collocated with GA
Colorado Springs	COSP	collocated with the MCS
Cape Canaveral	CAPE	collocated with GA
Kwajalein Island	KWAJ	collocated with GA
Hawaii	HAWAII	none

Notes: GPS personnel commonly refer to the sites by their mnemonic names also listed above. These mnemonic names will be used throughout this manual in diagrams as well as text.

MS SUBSYSTEMS FUNCTIONAL DESCRIPTION

Each MS is subdivided into subsystems. They are the Frequency Standard Element (FSE), the Receiver Element (RE), the Power Element (PE), the Control and Status Element (CSE), the Antenna Element (AE), and the Environmental Sensor Element (ESE). The following paragraphs describe the function of each subsystem. See MS Simplified Block Diagram in C&D.

Frequency Standard Element (FSE). The FSE provides a highly accurate and stable 5 MHz reference frequency to the Receiver Element (RE) via the Primary Distribution Unit (PDU), which uses this reference to phase lock crystal oscillators and establish the MS clock. Elements of the FSE include two Cesium Beam Frequency Standards (FS), two Battery Backup Units (BBU), which provide uninterrupted power to those units, and one PDU. The FS units provide 5 MHz outputs to the PDU Electronic Switch Module (ESM) and status information to the PDU Status Monitor Module (SMM). The PDU continuously monitors the 5 MHz outputs of both FS units for signal quality, stability, and phase shift. Control lines from the Control and Status Element (CSE) cause the PDU to output the 5 MHz reference of either FS1 or FS2. The PDU provides this information and an FS selection indicator to the CSE. The BBUs provide up to 8 hours of standby power to the FS units and status information to the CSE and the PDU. See Figure 1-17 for a simplified block diagrams showing interconnection of the FSE elements. The FSE at COSP differs slightly from other sites in that it is interconnected with the United States Naval Observatory (USNO) Multiple Frequency Standard System (MFSS) master clock. Figure 1-18 illustrates the COSP configuration. At COSP, FS1 and FS2 5 MHz outputs are routed into the MFSS. These references are compared with other references in the MFSS and a composite reference is returned. This composite reference is input into the PDU where the FS1 is input at other sites. The FS2 output becomes the reference for this station should the MFSS composite reference fail.

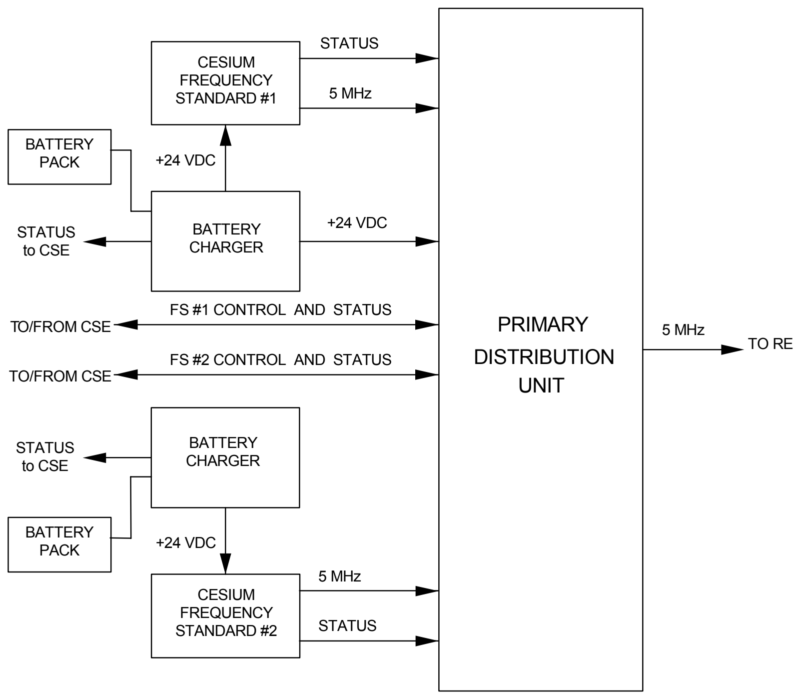


Figure 1-17. Frequency Standard Element, Simplified Block Diagram

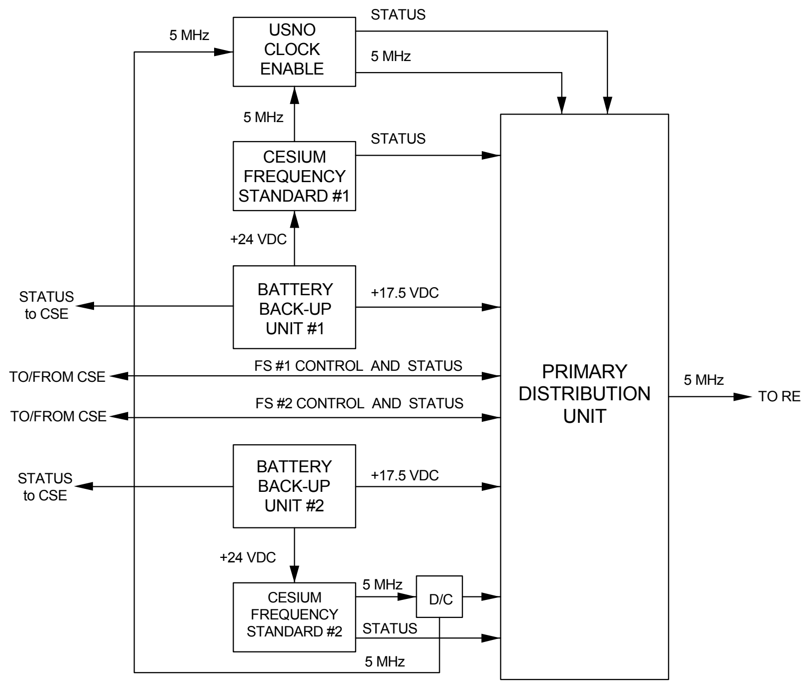


Figure 1-18. Frequency Standard Element, Simplified Block Diagram (COSP Only)

Receiver Element (RE). The RE processes L1 (1575.42 MHZ) and L2 (1227.6 MHZ) signals received from the Antenna Element (AE). The RE contains one 12 channel receiver chassis that processes the L1 and L2 RF signals. The RE receives a stable 5 MHz signal provided to the receiver chassis from the FSE Primary Distribution Unit. The receiver monitors signal quality, performs Pseudo-Range and Accumulated Delta Range (ADR) measurements, and extracts navigational data from those signals. After processing, the receiver chassis outputs signal quality data, PR measurements, ADR measurements, navigational data, and receiver configuration data through a RS-232 interface to the CSE. The CSE provides messages to the RE to control the receiver, and the Local Time Generation (LTG). The LTG function is also performed by the receiver chassis and provides the CSE with a Time of Week Z-count. Also located in the RE are two thermistors (temperature sensors), one located at the top front and the other located at the top rear of the RE rack. The thermistors provide the CSE with a voltage corresponding to the rack temperature to remotely monitor over-temperature of equipment. See Figure 1-19 for a simplified block diagram showing interconnection of the Receiver Element.

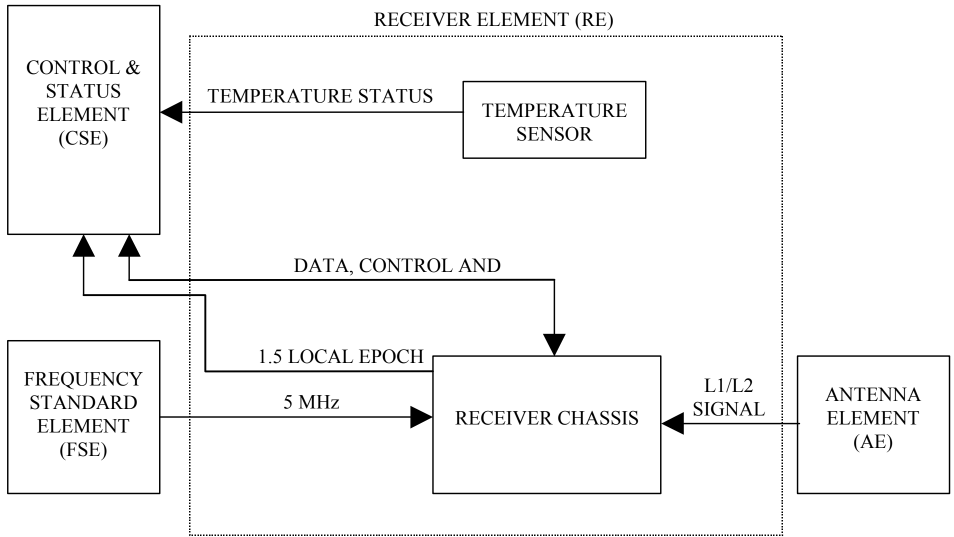


Figure 1-19. MS Receiver Element, Simplified Block Diagram

Power Element (PE). The PE contains a panel of status lights that display CSE status and one chassis that contains power control circuitry. The CSE status circuitry has been rendered non-operational by recent MS upgrades. Within the power control chassis is circuitry to monitor, control, and condition AC power that is distributed throughout the MS. This unit also contains a 24 VDC and a 5 VDC power supply. These DC voltages are distributed throughout the MS. At CAPE, the 24 VDC is provided to the Red/Black Filter Assembly, where it is distributed to the dewpoint and temperature sensor transmitter and to the pressure sensor. The 24 VDC is also used to derive the 12 Vdc, which is coupled with the L-Band signal and provided to the AE. The PE also contains circuitry to operate an Emergency Power Off (EPO) function. This function can be activated manually by rack mounted pull switches or remotely by control signals from the MS VME in the CSE. When an EPO is commanded by the MCS, the MS VME outputs a ground potential that activates the Remote EPO control on the PE logic board. See Figure 1-20 for a simplified block diagram showing interconnection of the Power Element.

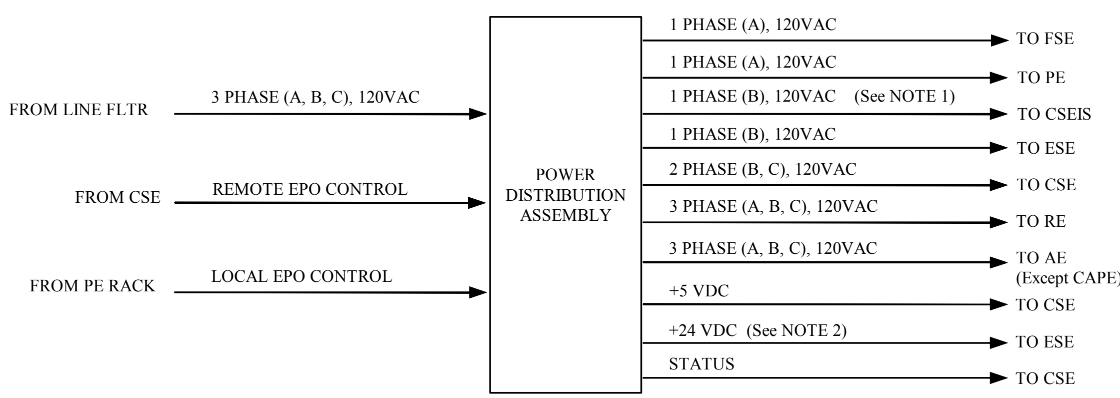


Figure 1-20. MS Power Element, Simplified Block Diagram

Control and Status Element (CSE). The CSE provides the overall control of the MS. The CSE sends control data to and receives status data from all MS elements. Additionally, it receives time, signal quality, and L-band data from the RE, and environmental data from the Environmental Sensor Element (ESE). The data input to the CSE is packaged and transmitted to the MCS. Packaged data received from the MCS is processed by the CSE and sent to control equipment in all MS elements. The subsystems that comprise the CSE are the Site Workstation (MS or GA), the LAN Printer, the Fiber Optic Ethernet Local Area Network (LAN), the Remote Power Management equipment, and the MS VME. See Figure 1- 21 for a simplified block diagram showing interconnection of the Control and Status Element.

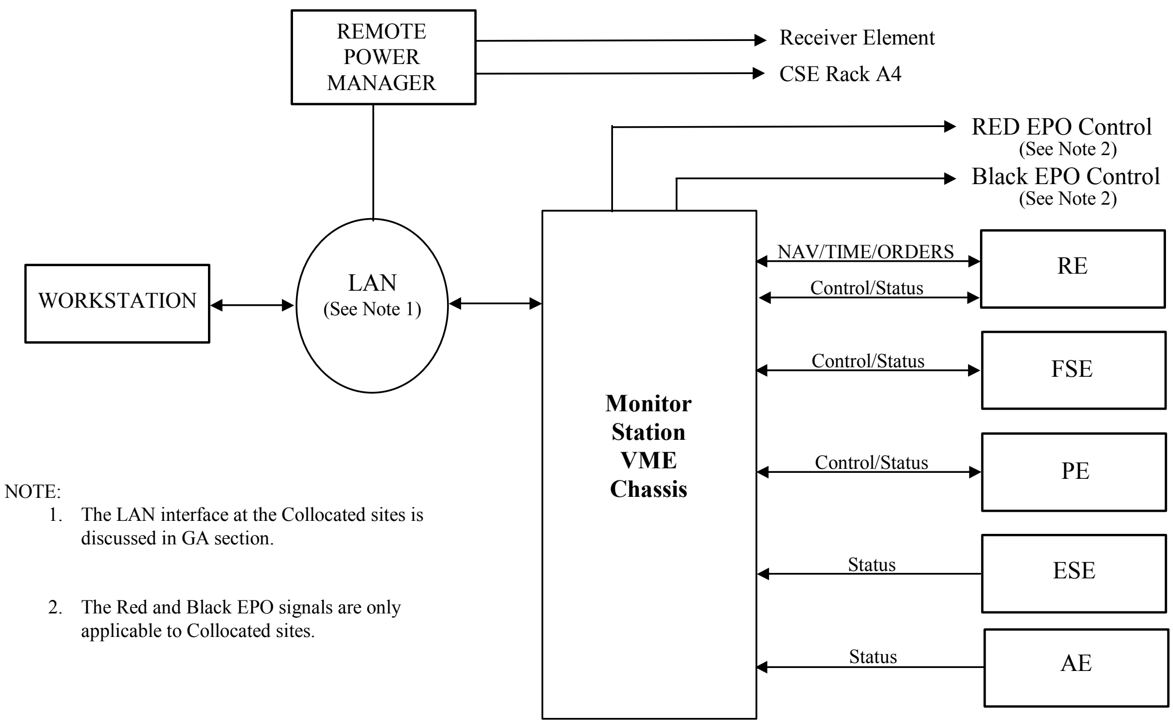


Figure 1-21. Control and Status Element, Simplified Block Diagram

Antenna Element (AE) Functional Description. The Antenna Element (AE) receives the L1 and L2 signals from GPS SV's, amplifies these signals, and routes them to the receiver chassis. The antenna assembly is mounted on a roof or tower in the proximity of and external to the MS equipment shelter. It is mounted in a manner as to eliminate the blockage of signals received from angles above 5 degrees from horizontal. The disk shaped portion of the antenna assembly provides a signal ground plane for the dipole antenna located in the center of the assembly. The antenna 12 Vdc power is supplied from the Red/Black Filter Enclosure and is provided via the L-band signal cable interface. The antenna does not provide fault or status data to the CSE. The built-in LNA amplifies the received signal approximately 53 dB and its output is cabled to the MSRE. See Figure 1-22 for a simplified block diagram showing the interconnection of the Antenna Element.

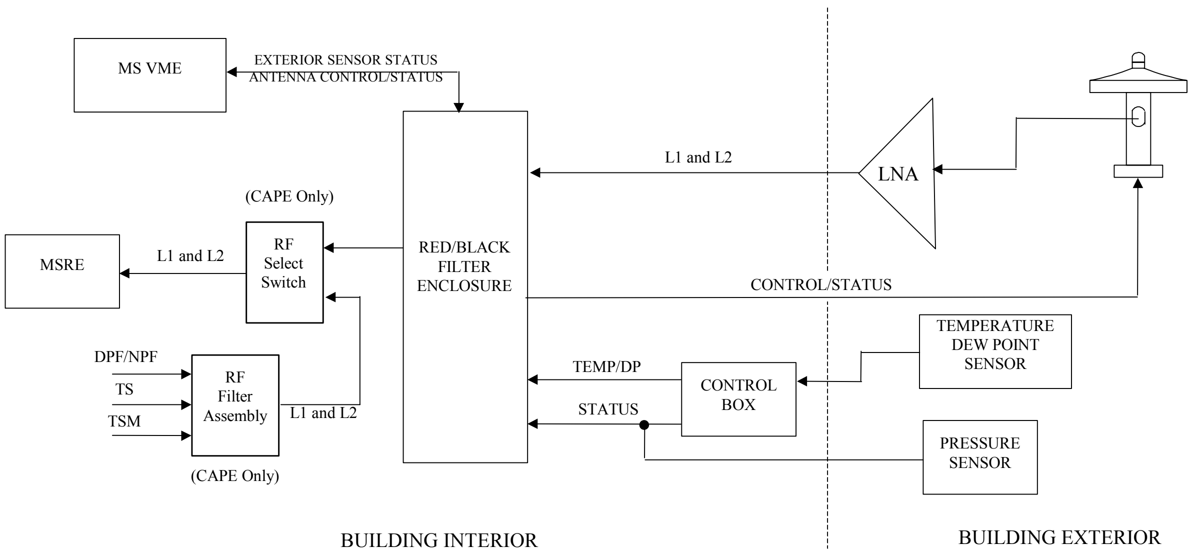


Figure 1-22. Antenna Element (AE), Simplified Block Diagram

Red/Black Filter Enclosure Functional Description. The Red/Black Filter Enclosure provides signal filtering for all power and signal lines routed outside the MS shelter (red area). This includes connection to the exterior environmental sensors and the AE (black area). Filtering prevents the emanation of potentially classified information from within the equipment shelter (red area). The filter assembly includes an externally mounted RF switch. Connected to this switch are the RF outputs of the AE and of the RF Filter Assembly, and the RF input to the RE. The switch enables the manual selection of the RF signal source to the RE, as directed by the MCS, to place the CAPE into either an operational MS mode, or Pre-launch Compatibility Station (PCS) mode of operation. See Figure 1-22 for a simplified block diagram showing the interconnection of the Red/Black Filter Enclosure

Environmental Sensor Element (ESE) Functional Description. The Environmental Sensor Element contains sensor equipment units to monitor environmental conditions inside and outside the MS equipment shelter. Inside, the temperature and humidity sensors are mounted on the side of the CSE equipment rack. The dew point and temperature sensor assembly and the barometric pressure sensor assembly are mounted on the MS equipment shelter external wall. A control unit for the external dew point and temperature sensor assemblies is wall mounted in the MS equipment shelter. External environmental data is used by the GPS Control Segment to more accurately calculate SV ephemeris. The ESE provides sensor and status data to the CSE. Figure 1-23 illustrates the interconnections of the ESE.

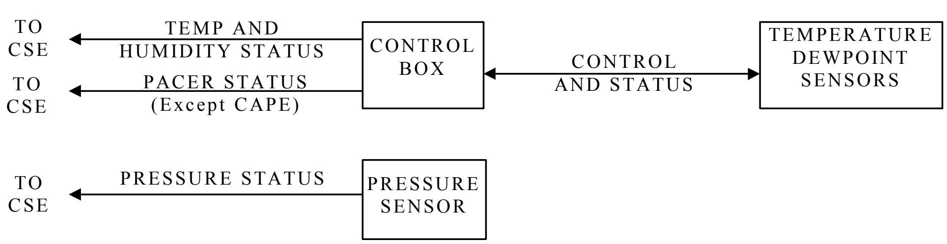


Figure 1-23. Environmental Sensor Element (ESE), Simplified Block Diagram

User Segment

The User Segment consists of all users of GPS information. The users are all those individuals and agencies who possess and use GPS receivers for navigation purposes. Although GPS is a military resource, operated by Air Force Space Command, civilian users can access and use it. GPS receivers have been developed for both military and civilian applications. How GPS will be used depends on the particular application and the capabilities of the user's receiver.

Block 14, Chapter 2
METEOROLOGY DATA STATION (MDS)
MKIVB SYSTEM DESCRIPTION AND PURPOSE

MARK IVB provides weather imagery and environmental database information collected via satellite observations to users and external communications/processing systems. MARK IVB receives and processes real time imagery and mission sensor data from polar orbiting satellites and imagery from geostationary satellites. It also receives data from satellites carrying the Mission 22 transmitter. Data can be simultaneously handled from one polar orbiting satellite and one geostationary satellite, or one Mission 22 satellite and one geostationary satellite.

MARK IVB enables weather personnel to manipulate and transform environmental databases using enhanced database and graphics capabilities. MARK IVB provides both automatic and semiautomatic dissemination of products to external systems. Information can be shared and distributed via the Internet. MARK IVB system equipment located in three major areas are listed below:

a. Antenna Area
b. Processing Area
c. Forecaster Area.

See figure 2-1 for system layout.

MARK IVB is a standalone system consisting of a tracking (polar orbiting satellite) antenna and a pointing (geostationary satellite) antenna, a Processing Area containing a high speed server with a Meteorological Data Workstation (MDW), and a Forecaster Area with a Meteorological Data Processing Terminal.

To prevent loss of data due to facility power failure, the Processing Area has a 10 kilovolts amperes (KVA) uninterruptible power supply (UPS). The Forecaster Area has an 850 volts-amperes (VA) UPS.

The three areas are physically separated. Communications are through fiber optic cables that connect the areas. The Antenna Area cannot be located more than 1500 feet from the Processing Area. The Processing Area cannot be located more than 31 miles from the Forecaster Area. See Figure 2-2 for equipment configuration.

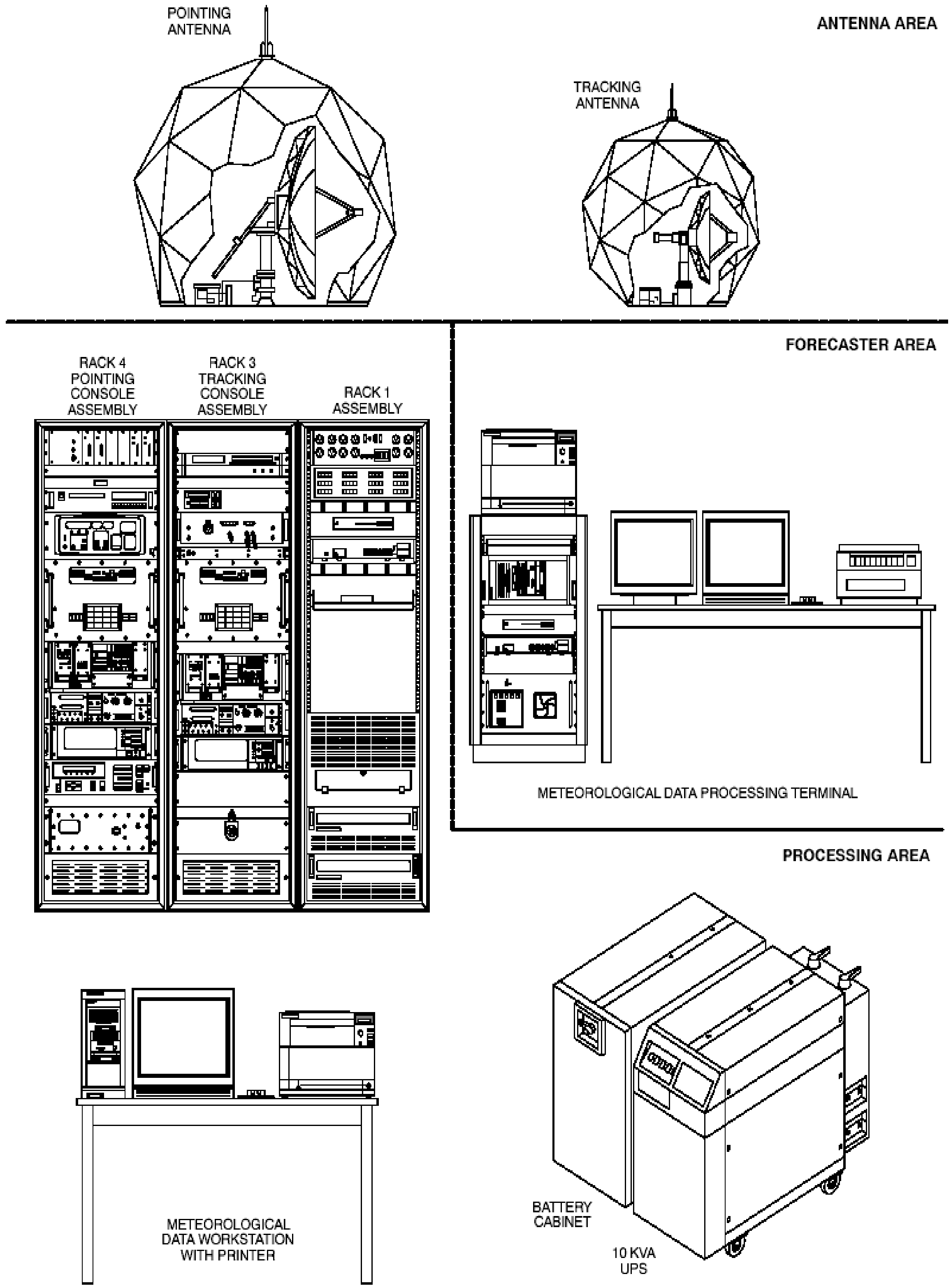


Figure 2-1 MKIVB System Equipment

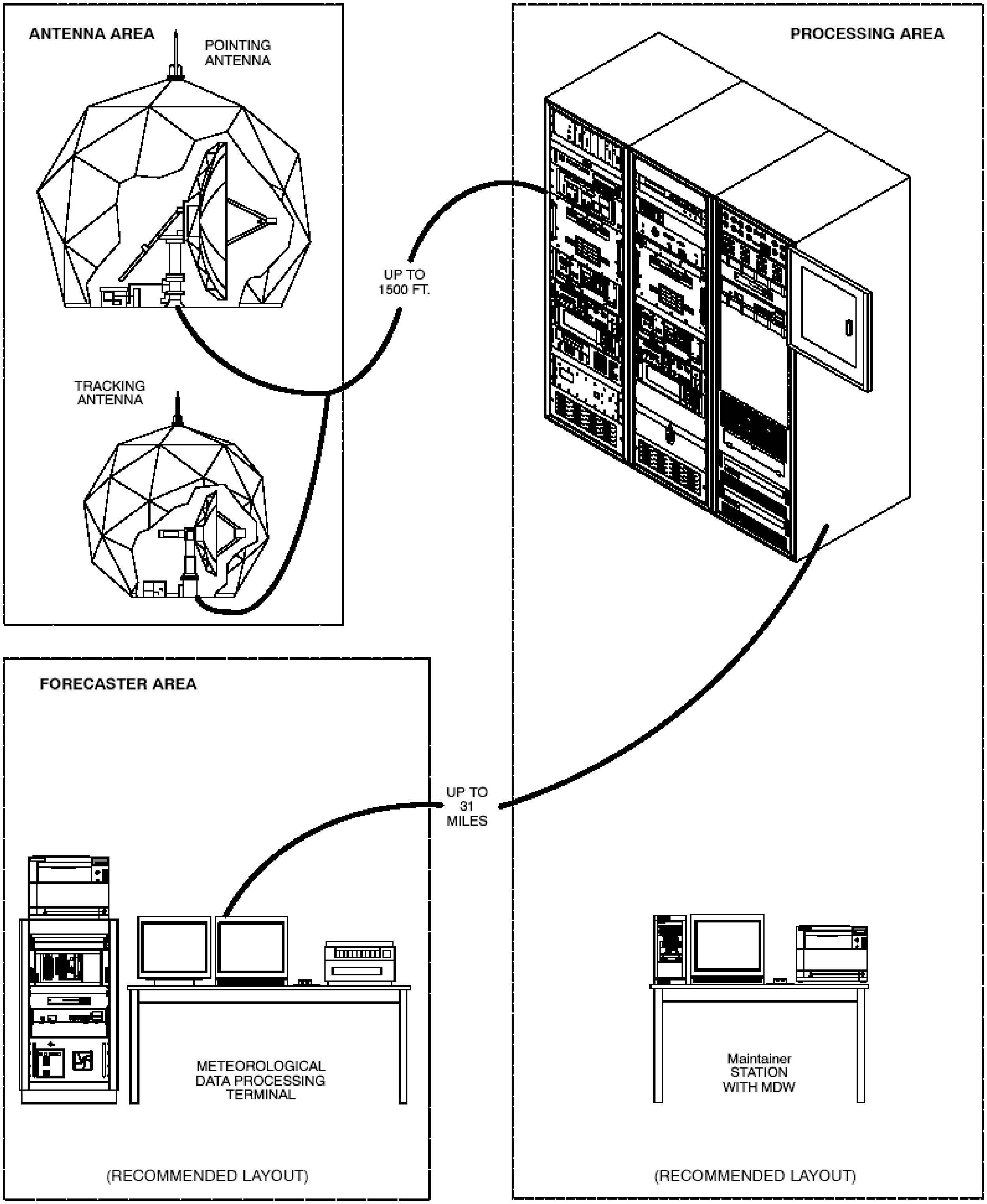


Figure 2-2. Fiber Optic Data Link Configuration

System Organization

The MARK IVB System can be functionally divided into two subsystems the Acquisition Subsystem and Product Control Subsystem. The Acquisition Subsystem receives and processes geostationary and polar orbiting weather satellite data from the antennas. This data is then sent to the Product Control Subsystem which will ingest or process the data and store it for later access. See figure 2-3 for subsystem breakdown.

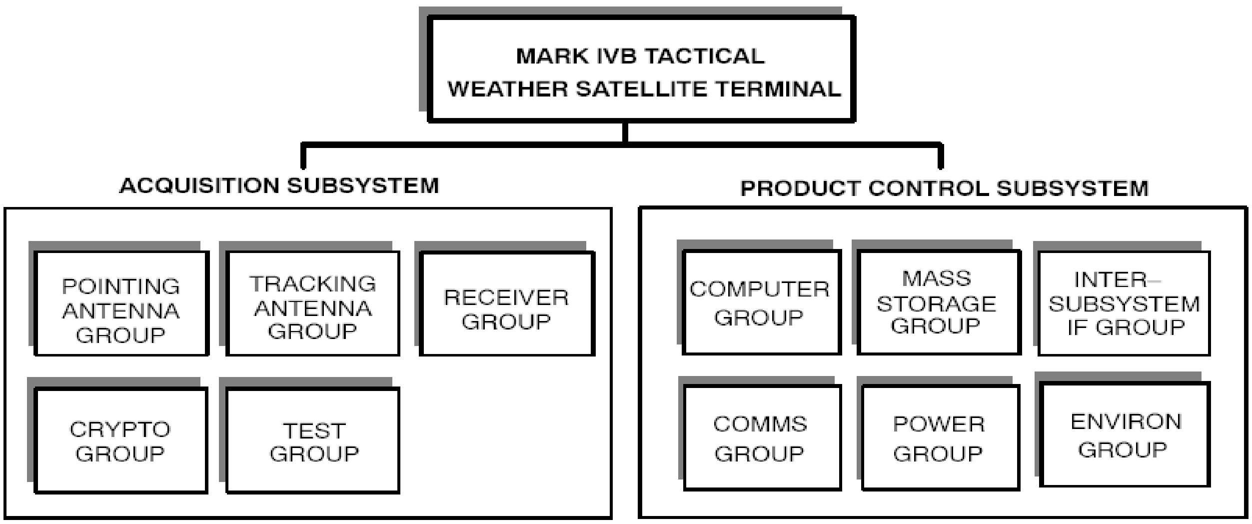


Figure 2-3. Subsystem Breakdown.

Acquisition Subsystem: The Acquisition Subsystem receives and processes geostationary and polar satellite data from the antennas. Data is then sent to the Product Control Subsystem via the Telemetry Receiver, Bit Synchronizer, and the Frame Synchronizer. The Acquisition Subsystem is divided into the following five groups:

a. Pointing Antenna Group
b. Tracking Antenna Group
c. Receiver Group
d. Crypto Group
e. Test Group.

Product Control Subsystem: The Product Control Subsystem receives decommutated, bit synchronized, and frame formatted data from the acquisition subsystem. The data is then laid down on the Disk Array Assembly for use by the forecaster applications. The two principal functions performed in the Product Control Subsystem are ingest (data processing) and database (storage) functions. The Product Control Subsystem is divided into the following six groups:

a. Computer Group
b. Mass Storage Group
c. Inter–Subsystem IF Group
d. Communication Group

e. Power Group
f. Environmental Group.

External Functional Interfaces: The system receives data from the satellites, processes it, and generates products which are sent to Users via communications links. The external communication interfaces originate from multiple points within the system. See figure 2-4 for External Functional Interfaces. The external interfaces are grouped as follows:

a. MARK IVB can receive data from:
   1. Polar Orbiting Satellite
   2. Mission 22 Satellite
   3. Geostationary Satellite
   4. Internet (other MARK IVBs)
   5. AFWA Communication Front End Processor (CFEP) Link
   6. Maintenance Interface
   7. NAVSTAR GPS Timing Signals.

b. MARK IVB can transmit data to the following:
   1. Internet (other MARK IVBs)
   2. Maintenance Interface
   3. Mission 22 Interface
   4. AFWA CFEP Link
   5. Satellite Imagery Dissemination System (SIDS)
   6. Generic Imagery Dissemination System (GIDS).

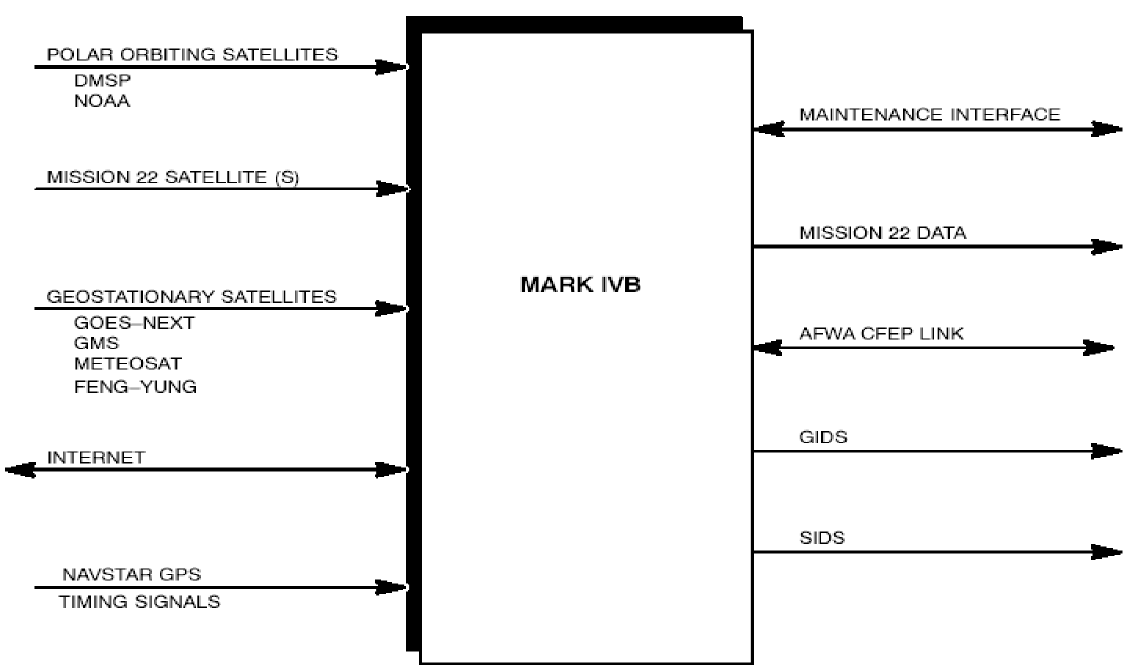


Figure 2-4. External Functional Interfaces

Satellite Data: MARK IVB can simultaneously receive and process data from one polar orbiting satellite and one geostationary satellite. MARK IVB can also receive and process data from two geostationary satellites, not simultaneously. Depending on the geographic location, MARK IVB can receive data from the following satellites:

a. Polar orbiting satellites
    1. DMSP satellite sends Real Time Data (RTD) and Mission Sensor Data (MSD).
    2. National Oceanographic and Atmospheric Administration (NOAA) satellite sends High
    3. High Resolution Picture Transmission (HRPT) imagery data
    4. Advanced Microwave Sounding Unit (AMSU) data.
    5. Mission 22 satellite(s).

b. Geostationary Weather Satellites
    1. Geostationary Operational Environmental Satellite – NEXT generation (GOES–NEXT) (USA).
    2. Geostationary Meteorological Satellite (GMS) (Japan).
    3. METEOSAT Meteorological Satellite (European Space Agency)
    4. Feng–Yung Meteorological Satellite (Chinese Space Agency).

Reference Time Source: MARK IVB receives an external reference time signal from the NAVSTAR Global Positioning System (GPS) Satellites. This signal is used to synchronize system operations for acquisition of satellite data. A Global Positioning System (GPS) receiver and a time code generator are used to provide very precise time-of-year information to the Mark IVB. As in all satellite ground stations, timing is a critical factor. The Mark IVB uses the timing information when calculating satellite rise times, grid overlays, and scheduling product transmissions.

AFWA Communication Front End Processor: The Air Force Weather Agency (AFWA) Communications Front-end Processor (CFEP) link is a link with Offutt AFB, NE for receipt of 1000 mb Height Field data. The CFEP data is transmitted by Offutt AFB to a designated File Transfer Protocol (FTP) site, where the User can access data through an Internet FTP session and download the data. This interface decodes only Uniform Gridded Data Field (UGDF) messages containing 1000 mBar Height readings.

Satellite Imagery Dissemination System: The Satellite Imagery Dissemination System (SIDS) is an output only function that transmits processed satellite weather imagery and data analysis to designated recipients. Data can be transmitted at User selectable data rates. Any product can be scheduled for automatic transmittal via the Product Distribution function.

Generic Imagery Dissemination System: The Generic Imagery Dissemination System (GIDS) is an output only function that transmits processed satellite weather imagery and data analysis from the database as image data files to designated recipients. Any product can be scheduled for automatic transmittal via the Product Distribution function.

Acquisition Subsystem

The Acquisition Subsystem receives and processes geostationary and polar satellite data from the antennas. Data is then sent to the Product Control Subsystem via the Telemetry Receiver, Bit Synchronizer, and the Frame Synchronizer. See Figure 2-5 for Acquisition Subsystem. The Acquisition Subsystem is divided into the following five groups:

a. Pointing Antenna Group
b. Tracking Antenna Group
c. Receiver Group
d. Crypto Group
e. Test Group

Figure 2-5. Acquisition Subsystem

Pointing Antenna Group

This equipment group is made up of the geostationary pointing antenna assembly and its associated pedestal control unit, or PCU. It is designed to receive RF transmissions from METEOSAT, GOES-NEXT, and GMS satellites.

The Geostationary Antenna is a 17 ft parabolic dish antenna capable of autotrack, program track or manual operation. The antenna uses DC electric drive motors to control movement in both the azimuth and elevation axes. It receives signals transmitted by geostationary satellites, then amplifies and provides these signals to the processing group equipment via the PCU fiber-optic link. Each axis of the antenna contains a synchro transmitter to monitor and report current antenna position and a mechanical limit switch assembly to prevent the antenna from being driven into its mechanical limits. This antenna also contains redundant Low Noise Amplifiers (LNAs), redundant L-band down-converters, and an L-band up-converter. See Figure 2-6 for Pointing Antenna Components.

Pedestal Control Unit (PCU): Each antenna is locally controlled and monitored by a PCU. The PCU receives antenna movement commands from its associated antenna control unit (ACU) (located in the processing area). A servo amplifier within the PCU converts the movement commands to DC control voltages for the azimuth and elevation motors. The PCU also monitors and reports antenna position and status to the ACU. The PCU accepts an amplified, down-converted RF signal from the antenna and transmits it to the receiver equipment in the processing area via a fiber-optic link.

The PCU also receives test signals from the test group equipment, also via the fiber-optic link, and routes the signals into the antenna signal path for testing purposes. The PCU also contains a Maintenance Operator Module (MOM) which allows maintenance personnel to manually operate the antenna.

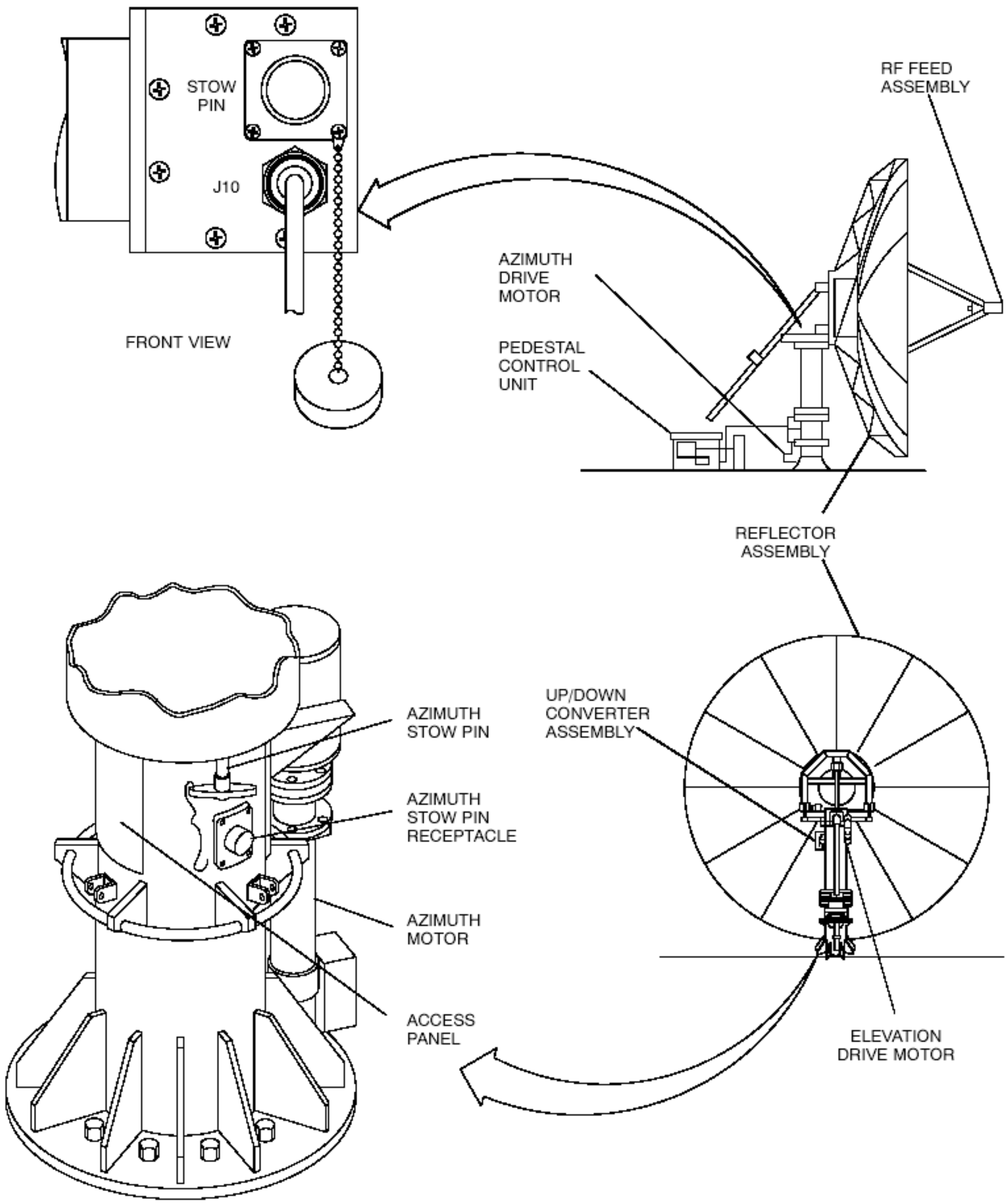


Figure 2-6. Pointing Antenna Components

Tracking Antenna Group

This equipment group is made up of the polar tracking antenna assembly and its associated PCU. It is designed to receive RF transmissions from polar orbiting NOAA, DMSP and mission 22 satellites.
The Polar Antenna Assembly is a 10 ft parabolic dish antenna capable of autotrack, program track, or manual operation. The antenna uses DC drive motors to control movement in the elevation and azimuth axes. It receives the radio frequency signals transmitted by polar orbiting satellites, amplifies them, and routes them to the processing group equipment via the PCU fiber-optic link. Like the pointer, this antenna uses synchro-transmitters and limit switches to monitor and report its movements. The polar antenna also contains redundant LNAs, L-band down converters, S-band down-converters, a single L-band up-converter, and an S-band up-converter. See Figure 2-7 for Tracking Antenna Components.

The PCU for the polar antenna is functionally identical to that of the geostationary antenna. See the geostationary antenna description given earlier for an explanation of the PCU.

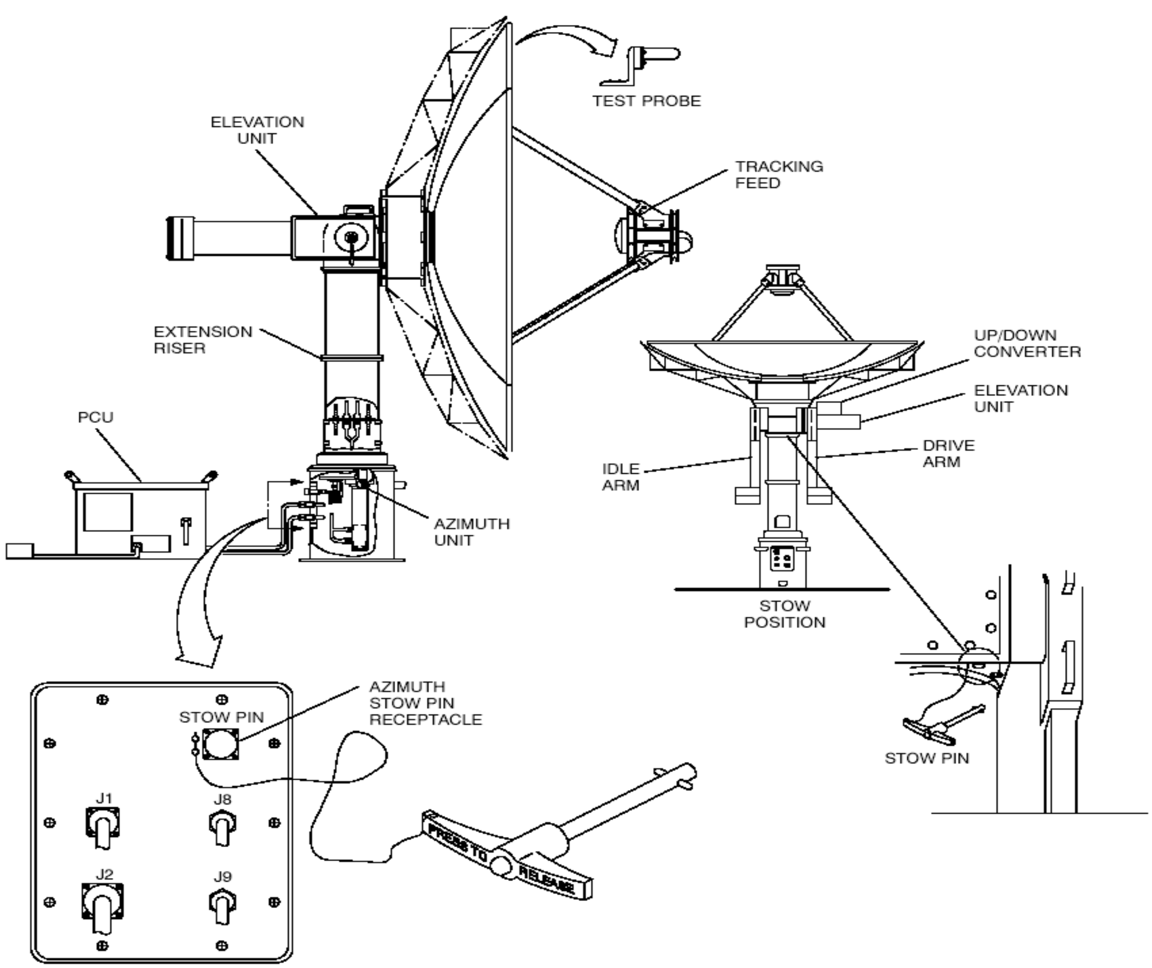


Figure 2-7. Tracking Antenna Components

Receiver Group

Under normal circumstances, the receiver, bit synchronizer, and frame synchronizer in rack 3 are responsible for processing polar data. The identical equipment in rack 4 handles the geostationary data. Equipment can be swapped between the two data paths to facilitate troubleshooting or to maintain operations under degraded conditions.
Solid-state switching circuits (within the switch controller) enable automatic or manual configuration of signal paths within the processing group equipment racks. See Figure 2-8 for Receiver Group equipment layout.

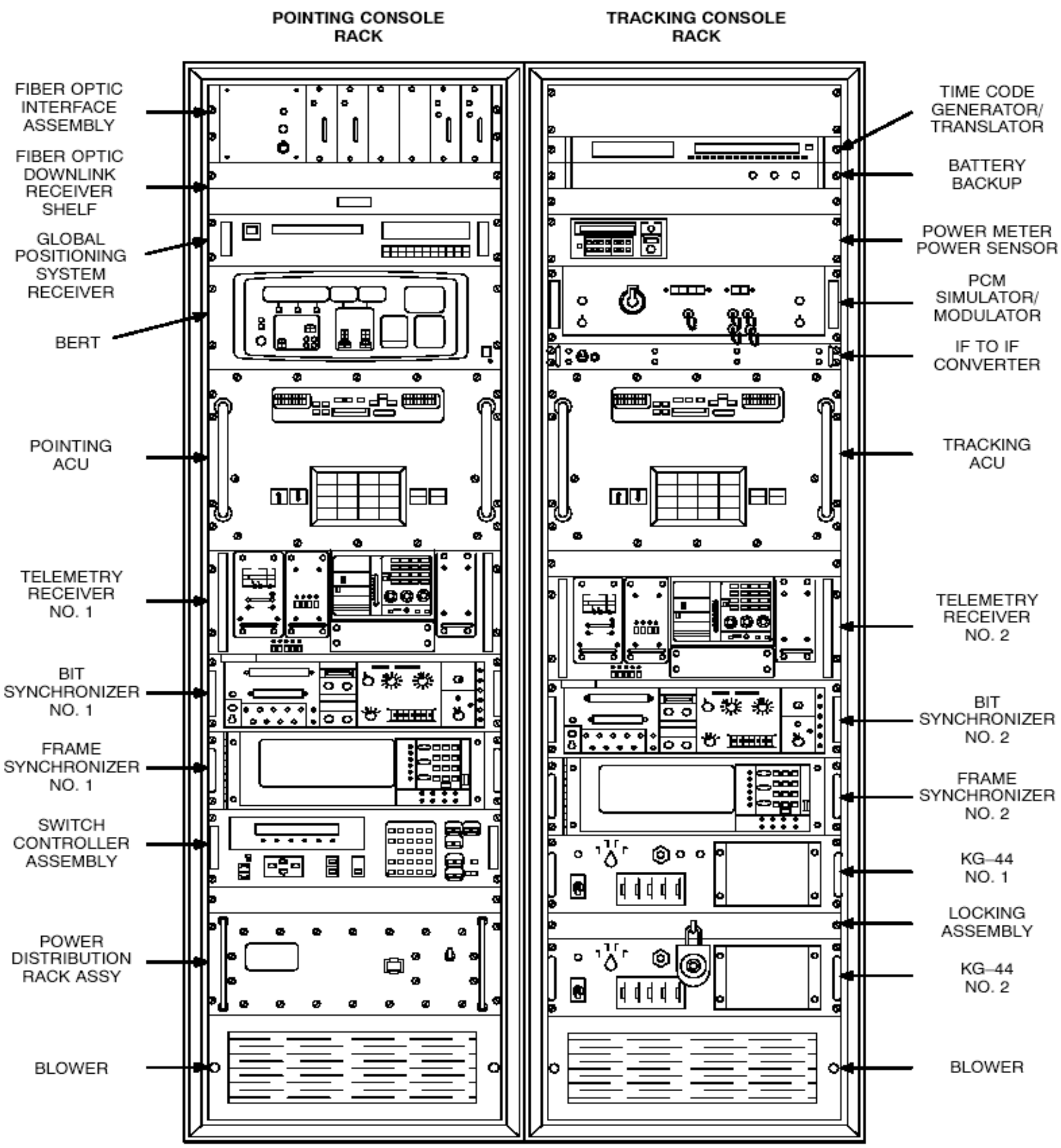


Figure 2-8. Receiver Group Equipment Layout

Antenna Control Unit (ACU): There are two ACUs. The ACU in rack 3 controls the polar tracking antenna while the one in rack 4 controls the geostationary pointing antenna. Each ACU controls the operating modes of its associated antenna, runs antenna hardware tests, and downloads operating software to the associated PCU at the antenna. A fiber-optic link provides the control and status interface between each ACU and its associated PCU.

Telemetry Receivers: The Mark IVB uses two telemetry receivers: one for polar data, and one for geo data. The receiver demodulates the satellite data and passes a serial bit stream to the bit synchronizer. In the tracking console, the receiver also strips off the AM tracking error signal and sends it back to the ACU where it is used for autotracking polar satellites. In the pointing console, the receiver provides a DC voltage representative of signal strength to the ACU where it is used as a pseudo-autotracking signal for geostationary satellites. This same DC level is used by both tracking consoles to determine autotracking thresholds.

Bit Synchronizers: The Mark IVB uses two bit synchronizers, each hard-wired to its associated telemetry receiver. The bit synchronizer receives the IF data stream from the telemetry receiver, bit synchronizes the data, and outputs digital data and clock. The encrypted data is routed to the KG-44 and mission 22 data is routed to its external user. All other data is routed to the frame synchronizer.

Frame Synchronizers: The Mark IVB contains two identical frame synchronizers, either of which can be configured to process any type of data. The frame synchronizer synchronizes on the raw digital data stream and clock pulse from the bit synchronizer, strips off unnecessary data, and sends the satellite data (in parallel format) to the input computer for ingest.

Crypto Group

The Tracking Console contains two KG–44s. The KG–44 decrypts polar satellite data from the appropriate Defense Meteorological Satellite Program (DMSP) satellite. If the data is encrypted, the KG-44 receives the clock and encrypted data from the bit synchronizer, and outputs the clock and decrypted data to the frame synchronizer. If the data is not encrypted, it is sent directly to the Frame Synchronizer.

Test Group

The test group consists of built-in Test Equipment (BITE) used to generate and monitor test signals. The equipment is used by the Mark IVB to perform periodic open or closed loop, end-to-end tests on the receive equipment.

During closed-loop testing, a test pattern is generated by the Bit Error Rate Tester (BERT), modulated onto a carrier by the PCM simulator/modulator, up-converted by the IF-to-IF converter, up-converted again by an up-converter on the antenna, and transmitted through a test probe mounted on the dish of the antenna. The signal is then received by the antenna, down-converted, demodulated by the telemetry receiver, bit synchronized, and routed back to the BERT for analysis.

During open-loop testing, a simulated data signal, generated in the PCM simulator/modulator, follows the same path through the system until it leaves the bit synchronizer. From here, the signal is routed to the frame synchronizer and finally to the MDS for analysis.

Bit Error Rate Tester (BERT): The BERT, under Mark IVB software control, outputs a serial data stream used to test the receiver group. The signal is routed through a PCM simulator/modulator, an IF to IF converter, an up-converter, and finally to a test probe on the edge of the antenna dish. The received signal is down-converted, demodulated, bit synchronized, and routed back to the BERT for analysis.

Pulse Code Modulation (PCM) Simulator/Modulator: As its name implies, the PCM simulator/modulator consists of both a PCM simulator and a modulator section. Depending on the type of testing to be done, the output from either the BERT or the PCM simulator will be routed to the modulator section. Either way, the PCM simulator/modulator outputs a 70 Mhz IF signal containing a modulated data stream. The data is routed to the IF-to-IF converter.

IF-to-IF Converter: This unit is basically a simple up-converter. It receives a 70 Mhz IF input signal and converts it to a 250 Mhz output signal.

Power Meter: An RF power meter measures the system noise power level for either antenna system or the output signal strength of the IF-to-IF converter.

<u>**Interfaces**</u>

Although not identified as a major equipment group, the interface connections play a vital role in linking together the components of the processing group. There are three types of interfaces:

a. Switch Controller
b. IEEE-488
c. RS-232
d. Fiber-optic

Switch Controller: The switch controller is the heart of the Mark IVB's ability to automatically configure itself for various operations. Under software control, the switch controller changes the interconnections between the different equipment in the acquisition subsystem processing group.

IEEE-488 Interface: This is a parallel-format control, status and data transmission interface. It connects most of the processing group equipment to the MDS using a "daisy-chained" bus. It enables the Meteorological Data Server (MDS) located in the Computer Group to access and remotely control the processing group equipment.

RS-232 Interface: This is a serial-format control, status and data transmission interface. It connects the MDS directly to the polar and geostationary ACUs, allowing the MDS to access and control these devices.

Fiber Optic Interface. Provides a control, status and data transmission interface between the processing group equipment and pointing and tracking group equipment.

Product Control Subsystem

The Product Control Subsystem receives decommutated, bit synchronized, and frame formatted data from the acquisition subsystem. The data is then laid down on the Disk Array Assembly for use by the forecaster applications. The two principal functions performed in the Product Control Subsystem are ingest (data processing) and database (storage) functions. See Figure 2-9 for Product Control Subsystem Groups and figure 2-10 for Product Control Subsystem Equipment. The Product Control Subsystem is divided into the following six groups:

g. Computer Group
h. Mass Storage Group
i. Inter–Subsystem IF Group
j. Communication Group
k. Power Group
l. Environmental Group.

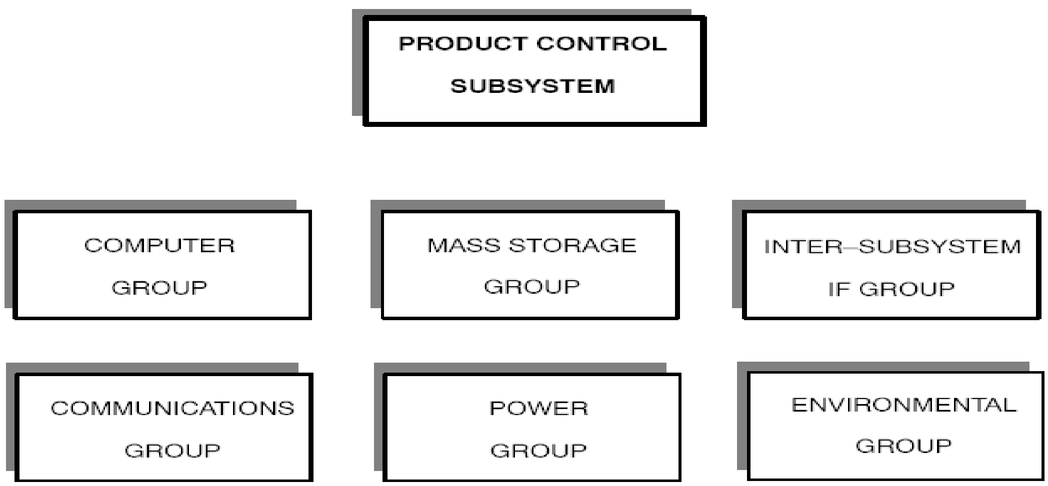


Figure 2-9. Product Control Subsystem Groups

<u>Computer Group</u>: The Computer Group receives satellite data from the Acquisition Subsystem, manipulates the satellite imagery/data and creates products when under control of the User. It also provides system control and status when under control of the Maintainer. The Computer Group includes the following components:

a. Meteorological Data Server (MDS) - The MDS processes satellite data from the Acquisition Subsystem and then stores this processed data on the Disk Array Assembly. The MDS is located in Rack 1.

b. Processing Area Meteorological Data Workstation (MDW) - The Processing Area MDW provides an interface to the system for routine operations and testing/troubleshooting, and provides full User and Maintainer functionality. The Processing Area Workstation consists of a workstation, monitor, keyboard and mouse, floppy disk drive, DAT drive, CD ROM drive, and color laser printer and print server.

c. Forecaster Area Meteorological Data Workstation (MDW) - The Forecaster area MDW acts as the primary interface between the Maintainer/User and the MARK IVB system. It contains the functionality to provide for power up/down, monitoring, control, data retrieval, data manipulation, and product creation/shipment. It is located in the Forecaster Area and includes two monitors, keyboard, mouse, floppy disk drive, DAT drive, and CD ROM drive.

Mass Storage Group: The Mass Storage Group stores the satellite imagery/data on the Disk Array for use by the User. The Disk Array also contains the operating system for the MDS. The Mass Storage Group includes the Disk Array Assembly.

The Disk Array Assemblies are the main storage devices for the system. A Disk Array Assembly is divided into two functional areas; system data storage and satellite data storage. The disk array configuration provides for expansion of both system disk and data disk storage capacity. The Disk Array Assemblies contain the following components:

a. Three 36.4 GB hard disk drives (HDDS)
b. Three 18 GB hard disk drives (HDDs)
c. Two 9 GB HDDs
d. One 8 GB, 4 mm Digital Audio Tape (DAT) drive used for loading system software, system software updates, weather products, and static databases (maps and climatological /topographical data)
e. Two 180 watt power supplies in each Disk Array

Inter–Subsystem IF Group: The Inter–Subsystem IF Group provides the necessary electrical interfacing between the MDS and the MDW and between the Product Control Subsystem and the Acquisition Subsystem. The Inter-Subsystem IF Group includes the following components:

a. Patch Panel. The patch panel provides a central location for manually changing cables to equipment in the processing area racks. The patch panel consists of 48 modular sockets and is located in Equipment Rack 1.
b. DR–11W Interface Panel. The DR–11W Interface Panel provides a signal interface between the DR–11W CCAs in the MDS and the Acquisition Subsystem Frame Synchronizers.

Communications Group: The Communications Group provides for the transfer of satellite data and control and status information between the Processing Area and the Forecaster Area, and between the local MDW and MDS. Data transmission between the Processing Area and Forecasting Area is through fiber optic cable. The communication equipment also provides a Local Area Network (LAN) connection to outside facilities for inter/intranet connection. The Communications Group includes the following components:

a. Fast Ethernet Switch - A Fast Ethernet Switch is located in both the Processing and Forecaster Areas, provides a Local Area Network (LAN) for all system Ethernet connections. The Ethernet switch also provides for future growth to allow interconnection of multiple systems through established networks. The switch supports both 10 Mbits per second and 100 Mbits per second transactions. Each switch provides eight RJ-45 ports configured at 100Mbps. In addition, each switch also provides one RJ-45 Comport for configuring the switch.

b. RS–232 Port Server - A Port Server is located in the Processing Area and Forecaster Area. The port server provides a means to convert RS–232 signals from the Processing Area UPS, Processing Area PEMU, and Forecaster Area UPS to an Ethernet signal for use by the system software
.

c. Fiber Optic Media Converter - A Fiber Optic Media Converter is located in the Processing Area and Forecaster Area. The media converters along with the fiber optic cable provide the communication link between the Processing Area and Forecaster Area. Each media converter is connected to the Fast Ethernet Switch located in its respective location.

d. Color Laser Printers - The color laser printer prints images from the MDW via an Ethernet print server interface. Hard copy printouts are 8.5 x 11 inches (up to 8.5 x 14 inches) with industry standards RGB color management.

e. High Definition Color Printer - The high definition color printer prints images from the MDW via an Ethernet print server interface. The maximum image size is 8 x 8.9 inches on an 8.5 x 11 inch media (photo quality paper or transparency). Printouts have a range of 16.7 million continuous tone colors.

f. Print Server - The print server provides ethernet connectivity to the printer and can queue up to 40 print requests. Connection to the printer is made via a single built in parallel connector which attaches directly to the printer. Power is supplied by an external AC converter.

Power Group: Provides protected power and power distribution throughout the Product Control Subsystem. The Power Group includes the following components:

a. 10 KVA UPS - Provides the equipment in the processing area with high quality, uninterrupted power during operation. In the event of a primary power failure, the UPS provides power until the batteries are exhausted or until primary power is restored.

b. 850 VA UPS - Provides the equipment in the Forecaster Area with high quality, uninterrupted power during operation. In the event of a primary power failure, the UPS provides power until the batteries are exhausted or until primary power is restored.

c. Power Environmental Monitoring Unit (PEMU) - The PEMU monitors the environmental sensors and controls power to the processing area equipment via the Power Distribution Assembly. The MDW in the Forecaster Area or Processing Area can control the PEMU through an RS–232 asynchronous serial link provided by the RS–232 Port Server. The

PEMU consists of an I/O station, five analog input modules, four digital AC modules, and one digital DC module mounted on a plate in Rack 1. The I/O station consists of a CPU board and power supply.

d. Power Distribution Assembly (PDA) - The Power Distribution Assembly (PDA) has three groups of four outlets, each with corresponding front panel power switches. The PDA front panel switches are always preset to control power distribution in Equipment Rack 1 to support normal MARK IVB System operations.

Environmental Group: Provides environmental monitoring and equipment protection. The Environmental Group includes the following components:

a. Barometer - This unit outputs a 0 to 15 V signal corresponding to 400 mb to 1100 mb and provides this measurement to the PEMU for relay to the system software. This unit is normally mounted on an exterior wall outside of the Processing Area.

b. Temperature and humidity sensor (exterior) - This wall mounted unit with an outside sensor probe outputs two signals of 4–20 ma corresponding to –60° C to +300° F for temperature and 0 to 100% for relative humidity.

c. Temperature and humidity sensor (interior) - This wall mounted unit outputs two signals of 4–20 ma corresponding to –60° F to +212° F for temperature and 0 to 100% for relative humidity.

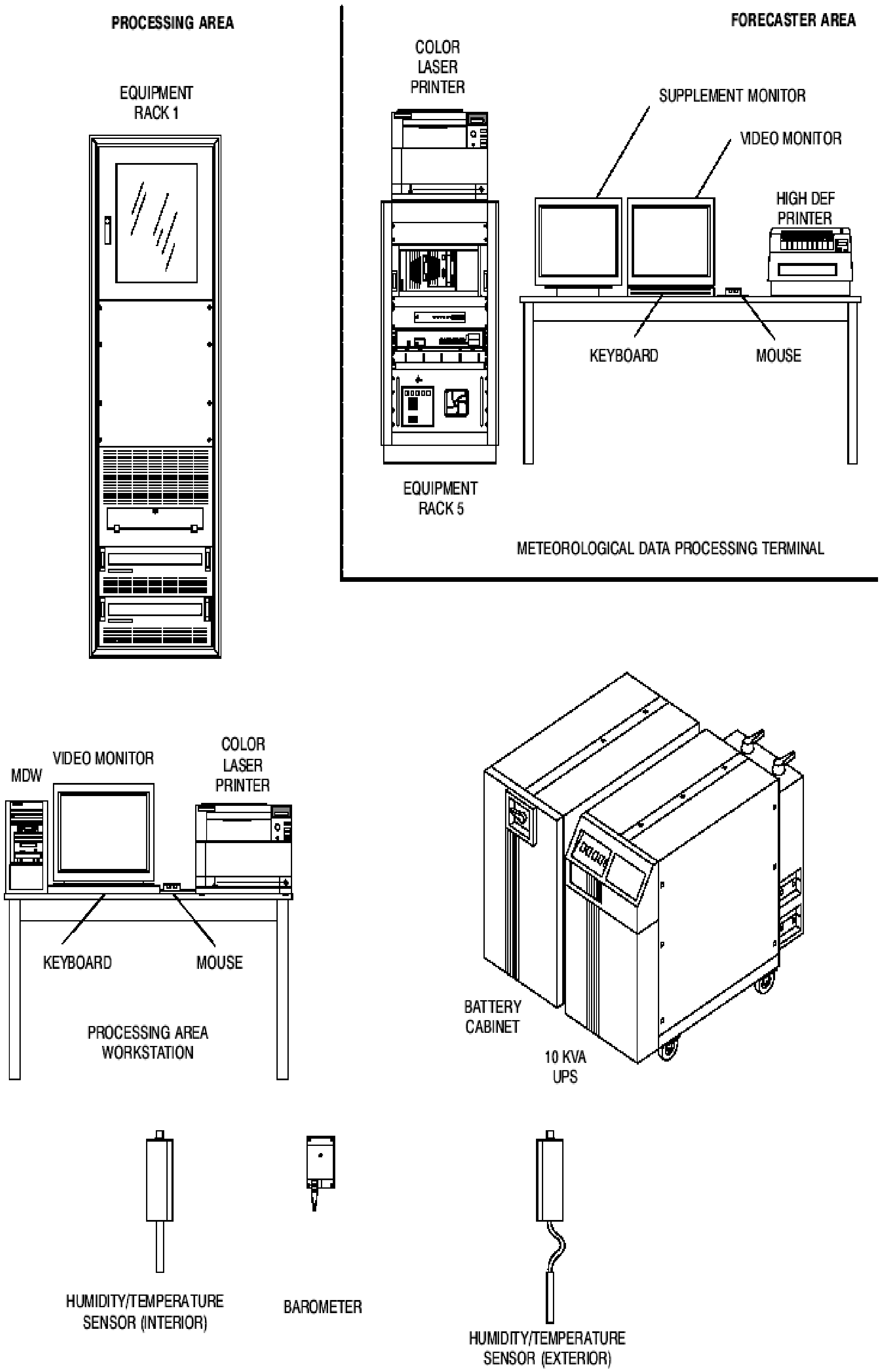
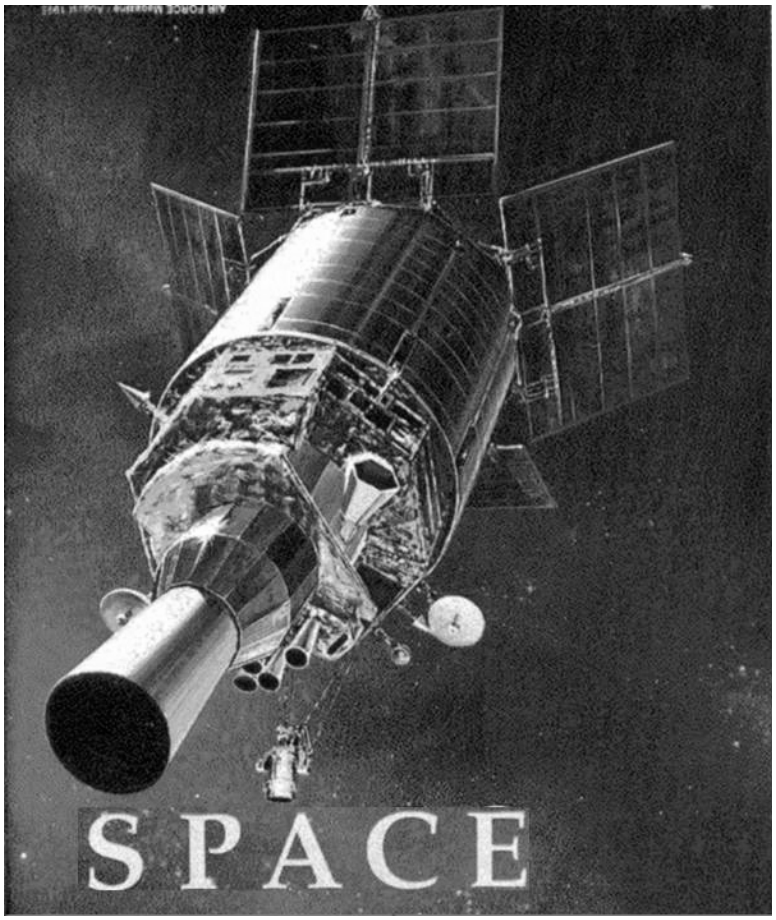


Figure 2-10. Product Control Subsystem Equipment

Block 14, Chapter 3
Defense Support Program

Section I

Satellite Ground Station



Mission

The Defense Support Program (DSP) provides a highly available, survivable and reliable satellite-borne surveillance system. It provides ballistic missile early warning and other information related to missile surveillance, launch, and detonation of nuclear weapons. During the Gulf War this program proved valuable in the detection and neutralization of SCUD launchers.

Each DSP satellite orbits at approximately 22,400 nautical miles above the equator in a geosynchronous orbit. This means that the satellite is always above the same point on the earth.

INFORMATION

Major Components

The Satellite Ground Station (SGS) provides reliable and maintainable receiving, transmitting, tracking and data processing equipment in support of the DSP satellites.
Since satellites do drift, or occasionally have problems making commanding necessary, corrections and control are normally handled by one of the two Satellite Ground Stations. All of the DSP satellites are within the field of view of one of these sites.

The SGS (Figure 3-1) is divided into three major sections. They are:

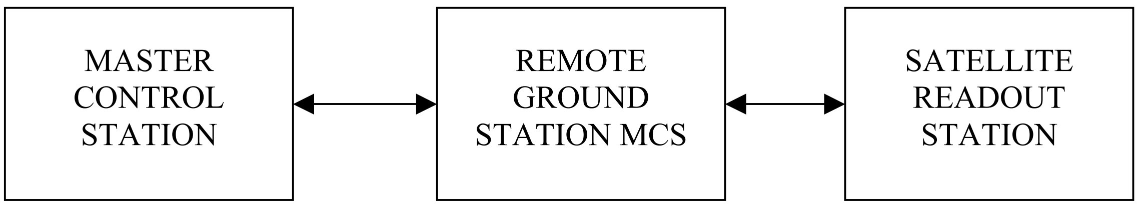


Figure 3-1, Satellite Ground Station Overview

Master Control Station (MCS) - The MCS performs several functions:

a) It monitors and interprets mission data. This includes reporting all significant events, and monitoring, interpreting, and reporting on the quality of all mission data.
b) It is responsible for monitoring satellite housekeeping functions including interpreting indications of malfunctioning satellite subsystems and analyzing troubles to identify faulty components.
c) Monitors the operational status of ground station equipment.

Remote Ground Station MCS1 (RGSM1)- The functions of the RGSM1 are as follows:

a) Format command data into serial ternary 1, 0, and S bits.
b) Receives L1/2 (I and Q) or L1 and discrete L2 downlink data/clock from the SRS and provides demultiplexing of L1/2 data and routing of L1 and L2 data/clock to the MCS.
c) Frame synchronizes, time tags, and formats the downlink data into L1, L2 and Coordinated Universal Time (UTC) messages.

Satellite Readout Station (SRS) - The SRS performs the function of transmitting commands and receiving the downlink data to/from the satellite. The SRS is divided into the two major sets called Transmit/Receiver Set (TR Set) and Radio Frequency Set (RF Set). As a 2E1X1, it is your responsibility to maintain all of the equipment within the SRS.

Transmit/Receive Set – The TR Set consists of equipment that supports the reception and processing of downlink satellite signals, and the generation and transmission of uplink satellite commanding and ranging signals. The TR Set consists of three downlink equipment strings and two uplink equipment strings used to interface with two antennas. There is one downlink string for each of the two antennas and a third downlink string in standby (connects to antenna 1 or 2). The downlink string consists of an Uplink/Downlink Switch (UL/DL SW), an RF Unit, a Link 1/2 Receiver, and a Link 2/Link 4 Receiver. Each uplink string is dedicated to an antenna and they consist of an UL/DL SW, an RF Modulator, and an Echo Check Receiver. The major functions of the TR Set are downlink function, uplink function, test and monitor function, and control and status function. The MCS normally controls these functions via the RGSM1. The TR Set performs the following functions:

1) Receive, demodulate, and process radio frequency (RF) signals received simultaneously from two satellites via the RF SET.
The RF signals from each satellite are L1 or L1/2 carrier frequency at 2232.5 MHz, discrete L2 carrier frequency at 2237.5 MHz and maybe L4 carrier frequency at 2234.95 MHz.

2) Demodulate and process serial data and provide data to the RGSM1.

3) Perform adaptive equalization to alleviate propagation anomalies caused by nuclear events.

4) Provide the RF Set with monoscan modulator drive signals along with elevation and azimuth error signals and automatic gain control (AGC) signals derived from the downlink L2 RF carriers.

5) Receive, demodulate and detect the L4 impact and provide alarms to MCS

6) Receive two simultaneous independent 1/0/S serial command data signals from the RGSM1 and modulate this data on two L3 carrier at 1791.748 MHz. Both L3 are routed simultaneously to RF Set string 1 and string 2 equipment for amplification and transmission to two satellites.

7) Demodulate a sample (echo signal) of the uplink L3 RF carriers to recover the 1/0/S serial bit stream and provide these bit streams back to the RGSM1. This is required to ensure the command send is correct.

8) Measure two-way range to two satellites simultaneously by modulating the L3 carriers by the pseudorandom noise (PRN) ranging sequence and measuring the round trip delay of transmission to the satellites and back to the TR Set via the L2 frequency.

9) Send status to the RGSM1 and receive control data from the RGSM1. In addition, provide the capability for observing status and providing control on the TR Set equipment front panel.

10) Send diagnostic status to the RGSM1 and route pertinent signals to the Spectrum Analyzer and Power Meter that will enable the RGSM1 to determine and isolate faults to line replaceable units (LRU) within the TR Set equipment.

Radio Frequency Set – The RF Set receives Link 1 or Link 1/2, Link 2 and/or Link 4 (impact sensor) downlink signals in the 2.2 to 2.3 GHz bandwidth. The RF Set can process these signals in a benign (normal radiation environment), an interference, or a scintillation environment. Downlink signals can be received by the antenna main feed horn, the four tracking/scintillation feed horns, and the eight interference suppression feed horns.The RF Set also transmits the Link 3 signals in the 1.761 to 1.842 GHz range.

The RF Set interfaces with the RGSM1, TR Set and Antenna Control Group (ACG) to receive telemetry and ranging data from a satellite, transmits commands and ranging data to a satellite, and provides for automatic or manual tracking of the satellite signal. The RF Set performs the following functions:

1) Receives, amplifies, and conditions L1 or L1/2, discrete L2, and L4 downlink signals and routes the downlink signals to the TR Set.

2) Receives and amplifies L3 uplink signals from the TR Set and routes the uplink signals to the Antenna Control Group.

3) Inserts L1 or L1/2, discrete L2, or L4 test signals from the TR Set into the Antenna Control Group downlink path to support performance tests and fault isolation.

4) Receives antenna position error signals from the TR Set, processes those signals and routes position signals to the Antenna Control Group.

5) Receives control messages from the RGSM1, develops RF Set control messages and Antenna Control Group control signals, and routes control signals to the Antenna Control Group.

6) Receives status from the Antenna Control Group, develops RF Set and Antenna Control Group status messages, and sends messages to the RGSM1.

7) Monitors uplink signals in the RF Set from the High Power Amplifier System samples and routes the monitor signals to the TR Set.

8) Monitors uplink signals from the Antenna Control Group via the vertex horn and routes the monitor signals to the TR Set.

9) Monitors downlink signals from the Antenna Control Group and routes the monitor signals to the TR Set.

10) Controls Antenna Control Group functions from the RF Set Workstation in Local mode. Local operation is only used as a backup or for maintenance actions. The Remote operations are performed using the RGSM1 Workstation (normal operations).

Uplink

In order t have a working satellite system we need to maintain the satellite's health and orbit. This is the ultimate purpose of uplink transmission - to control and maintain the satellite. We will now discuss the particular aspects and signal paths of uplink transmission within the SRS. The SRS has two separate paths that function identically. This gives the SRS the ability to transmit to two satellites at the same time. Uplink equipment string 1 is connected to RF Set equipment string 1 (antenna 1) and uplink string 2 is connected to RF Set equipment string 2 (antenna 2). See Figure 3-2 for simplified block diagram, (both Uplink and Downlink).

Uplink commands originate from the Operator Workstation in the MCS. These commands are sent from the MCS, using TCP/IP format, to RGSM1 via fiber. The RGSM1 converts the command from TCP/IP format into a serial ternary 1, 0, and S bits. Once this is accomplished the ternary data along with a 1 KHz clock are sent RF Modulator. The RF Modulator's primary function is to FSK the ternary data (1's = 95 Hz, 0's = 76Hz, and S's = 65 Hz). While the FSK process is taking place, the 1 kHz clock is being delayed the same amount of time. The frequencies are AM modulated with the clock to create a L3 baseband signal.

The RF Modulator also receives a Pseudorandom Noise (PRN) ranging code from the L2/L4 Receiver. In the uplink path, L2/L4 Receiver generates a pseudorandom noise serial bit stream to be summed with the baseband signal. The purpose of the satellite ranging function is to compute the range to the satellite. A comparison of the uplink PRN signal to the return delayed downlink PRN signal and the delay between the two calculates the distance to the satellite.

The RF Modulator phase modulates the composite baseband onto a L3 carrier of 1791.748 MHz. The signal is then sent to the bandpass filter. The bandpass filter is used to filter off harmonics produced in developing the carrier frequency. From here the L3 carrier signal is passed on to the Uplink/Downlink Switch.

The Uplink/Downlink Switch (UL/DL SW) routes the RF signals from the TR Set to the RF Set. This unit is part of the TR SET. The UL/DL SW routes the signal to the RF Test Assembly.

The RF Test Assembly receives the L3 uplink signal from the TR Set. It amplifies the uplink signal and then divides the signal into two equal signals. The two signals are routed to the High Power Amplifier System.

The RF Set HPA System amplifies each of the signals. It consists of two identical Klystron amplifiers, with common RF waveguide switching assembly. The Test Assembly outputs are applied to the inputs of the Klystron amplifiers. The output of each Klystron amplifier has an output power of 2 KW. When operating in the combined mode, the HPA system can provide a 4 KW nominal output signal. The output of the HPA System is fed to the RF Waveguide Switching Assembly, through the Diplexer and the antenna feed assembly.

The RF waveguide switching assembly is used to combine the outputs from the Klystron amplifiers or switch individual outputs to the antenna or a dummy load.

The Diplexer primary purpose is to allow the simultaneous transmission and reception of different signals. Thus, while transmitting the uplink frequency of 1791.748 MHz, we can still receive L1 or L1/2, L2, and L4 downlink signals.

The antenna transmits commands and ranging data to the satellite. The transmission of L3 RF energy from the HPA System is through waveguide and rotary joints which allow rotation of the antenna at the elevation and azimuth axis. The RF energy continues through the diplexer and the center feedhorn, reflects off the 7.5 ft. sub-reflector to the 60 ft. main reflector, then L3 is transmitted into space.

Echo Check

Echo Signal is a sample of the transmit signal taken by the vertex horn. The Echo Signal is used to check the accuracy of the transmitted signal. If the echo check command is not identical, a command is sent to stop the command transmission. This is a safety to ensure the correct commands are being transmitted.

The Vertex horn is located in the sub-reflector of the antenna. The Echo Signal is passed to the RF Test Assembly. The RF Test Assembly routes the echo signal to the UL/DL SW in TR Set. The

UL/DL Switch routes the Echo Signal to the L3 Echo Check Receiver. The Echo Check Receiver demodulates the RF Echo Signal and provides echo serial ternary data (1, 0, S) and clock to the RGSM1. The ternary Echo Signal is in the same format of the original command data.

Downlink

Commanding the satellite is a critical, but if we cannot receive valid information from the satellite the process is useless. Let's examine how we go about receiving the downlink data from the satellite. There are several links associated with receiving data from a DSP satellite: a 2232.5 MHZ called L1 (Mission or Sensor data) or L1/2 (multiplexed L1 & L2), 2237.5 MHz is L2 (State of Health), and 2234.95 MHz is L4 (Impact data). We will mainly be discussing the processing of the primary signals.

The antenna reflector and microwave receiving equipment consist of the five feedhorn array, a diplexer, and the selective filter that provide reception of telemetry and ranging data from the satellite.

The antenna receives the downlink data from the satellite. This is the same parabolic antenna used in the Uplink Section. The incoming signal is picked up by the main reflector, reflected up to the sub-reflector, and then into the Feedhorn Assembly.

The Feedhorn Assembly consist of five receive feedhorns. They produce a main channel signal from the center feedhorn and tracking channel signals from the four tracking feedhorns. The main channel consists of L1 or L1/2, L2 and may contain L4 alarm signals. The main signal is applied through the diplexer and filter to the Low Noise Amplifier within RF Amplifier Assembly (RFAA). The tracking signals are applied to selective filters which pass only the received frequencies of interest and reject all others. The frequencies from the selective filters are applied to the RFAA tracking inputs for processing.

Interference suppression (IS) minimizes the effects of interference sources surrounding the antenna, thereby enhancing the purity of the main downlink RF signal. Interference suppression is accomplished by sensing, processing, and canceling emissions adversely affecting reception of signals from the satellite.

This function is implemented by the antenna interference suppression feedhorn array and the Interference Suppression Assembly (ISA). The interference feedhorn array consists of eight feedhorns (A thru H) in a circular array around the periphery of the antenna five feedhorn array. The eight feedhorns are applied to eight separate filters. The filter outputs IS signals from the feedhorn opposite pairs and they are applied to 180-degree hybrids in the ISA.

The RFAA primary function is to receive, amplify, and process the signals from the main and tracking channels, and from the ISA. The receive signal is routed through the switch to the input of the channel A or B Low Noise Amplifier (LNA A or B). The signal is amplified by the LNA (55 dB of gain) and routed through the phase shifter, variable attenuator, summer, directional coupler, and delay line. The phase shifter and attenuator are used to set the phase and amplitude of the main channel with respect to the tracking channels. The summer is used to inject the error signal from the scanner/comparator onto the main channel for pseudomonopulse modulation.

Pseudomonopulse autotracking is a method of tracking in which antenna circuitry develops azimuth and elevation error signals from tracking error horn inputs to a comparator circuit, biphase modulates it and modulate (AM) the resultant error signal with the MAIN signal. The TR Set Link 2/Link 4 Receiver demodulates the signal and produces error currents proportional to the amplitude modulation. The antenna is than pointed appropriately to correct for the errors. The primary advantage of pseudomonopulse is that it requires less equipment.

The RFAA sends the RF MAIN signal with interference to the RF Set ISA where the signals are processed to cancel the interference. The ISA processes the outputs from the interference suppression feedhorn array into canceling signals. The ISA sends back the RF MAIN signals minus the interference for final amplification by an RFAA RF Driver Amplifier. The RFAA sends amplified and processed MAIN signal to the TR Set.

The TR Set UL/DL SW switches the RF signals from the RF Set (normal operation) or up to three signals from the Test and Monitor Switch (loop test operation) to the RF Unit. We are only going to talk about the processing the MAIN signal. The MAIN signal is switched to the RF Unit and the Link 2/ Link 4 Receiver. The Uplink/Downlink Switch is also used to route antenna control signals from the Link2/Link 4 Receiver to the RF Set equipment.

The RF Unit function primarily as an RF downconverter and bi-phase shift keyed (BPSK) or quadrature-phase shift keyed (QPSK) demodulator. The RF Unit accepts up to three RF channels. The RF inputs are routed to three signal selection circuits, which are controlled by inputs from the Link 1/2 Receiver. The selected signal is downconverted to an IF signal and demodulated. In demodulating the IF, an RF local oscillator signal generated by the Link 1/2 Receiver is used to compensate for the minor variations in the S-band frequency.

If the received RF signal is L1 (BPSK modulated), the demodulated RF Unit output consists of an "I" channel baseband signal. If the received RF signal is L1/2 (QPSK modulated), each RF channel is processed to produce two baseband information channels, designated "I" and "Q" channels. The resultant L1/2 channel I and Q baseband output (six outputs total, three "I" and three "Q") are applied to the input of the L1/2 receiver. If the receive signal is L1/2 with the same data on "I" and "Q" channels (I=Q), it is effectively a BPSK modulated signal and only I channel outputs are provided to the Link 1/2 Receiver. The RFU is controlled by the Link 1/2 Receiver.

The Link 1/2 receiver performs the following functions:

1. Provide the local oscillator signal used by the RF Unit to tune to the satellite frequency and demodulate the IF signal.
2. Synchronizes the bit timing signals to that of the incoming data.
3. Digitizes the analog baseband inputs.
4. Equalizes the digitized signal to minimize the distortion (scintillation) induced by transmission through the atmosphere.

If the applied "I" and "Q" data is L1, the processing forces "I" data to appear on "I" channel. The "Q" data is forced to zero, since there is no "Q" data in a L1 BPSK transmission. If the data was encoded by the satellite, the Decoder circuits perform Viterbi decoding of the synchronized "I" data. The resulting Link 1 data and clock has a data rate of 1.024 Mbps, and is routed to RGSM1.

If the applied "I" and "Q" data is L1/2, the processing forces "I" data to appear on "I" channel and "Q" data to appear on "Q" channel. The MAIN channel of digitized baseband is routed to an adaptive equalizer, which continually evaluates each channel to determine the effect scintillation has had on the L1/2 signal. A weighted correction factor minimizes the effects of scintillation. The outputs of the adaptive equalizer circuit are applied to a decoding circuit for Viterbi decoding of the synchronized I and Q data. The resulting L1/2 "I & Q" data and clock has a data rate of 1.280 Mbps, and is routed to RGSM1.

The L2/L4 Receiver primary function is to demodulate the RF L2 (discrete) carrier to IF. It provides L2 data and clock signals with a data rate of 1 or 128 kbps to the RGSM1. The primary data rate for L2 is 128 kbps. The L2/L 4 Receiver also processes L4 signals, computes range to satellite, and demodulates and processes the pseudomonopulse error signals from the main channel downlink by the RF Set to produce antenna control signals.

The satellite impact sensor assemblies transmit L4 carrier. The only time L4 signal is downlinked is when either or both satellite impact sensor assemblies are turned on by an impact or test signal.

The L2/L4 Receiver Ranging Processor performs both uplink and downlink functions. The L2/L4 Receiver generates a PRN signal and sends it to the RF modulator to be added to the transmit signal. The downlink signal from the satellite, which is modulated with the PRN ranging data, is received and processed in the RF Set. This downlink signal with ranging is processed by the RF and IF Processor the same as any downlink signal. The demodulated L2 baseband output with the ranging data is applied to the Ranging Processor. Here the PRN data is extracted from the data, processed, and applied to the Link 2/Link 4 Receiver Single Board Computer. The Single Board Computer compares the uplink PRN signal to the return delayed downlink PRN signal and by measuring the delay between the two calculates the distance to the satellites. The range value is output to the RGSM1 via a Control and Status LAN.

The L2/L4 Receiver amplitude demodulate the IF signal to extract the antenna autotrack error signals consisting of azimuth and elevation errors. It produces the antenna tracking control signals to support the RF Set in positioning the antenna for best satellite signal reception. The antenna control signals are switched through the Uplink/downlink Switch to the Antenna Control Group via RF Set.

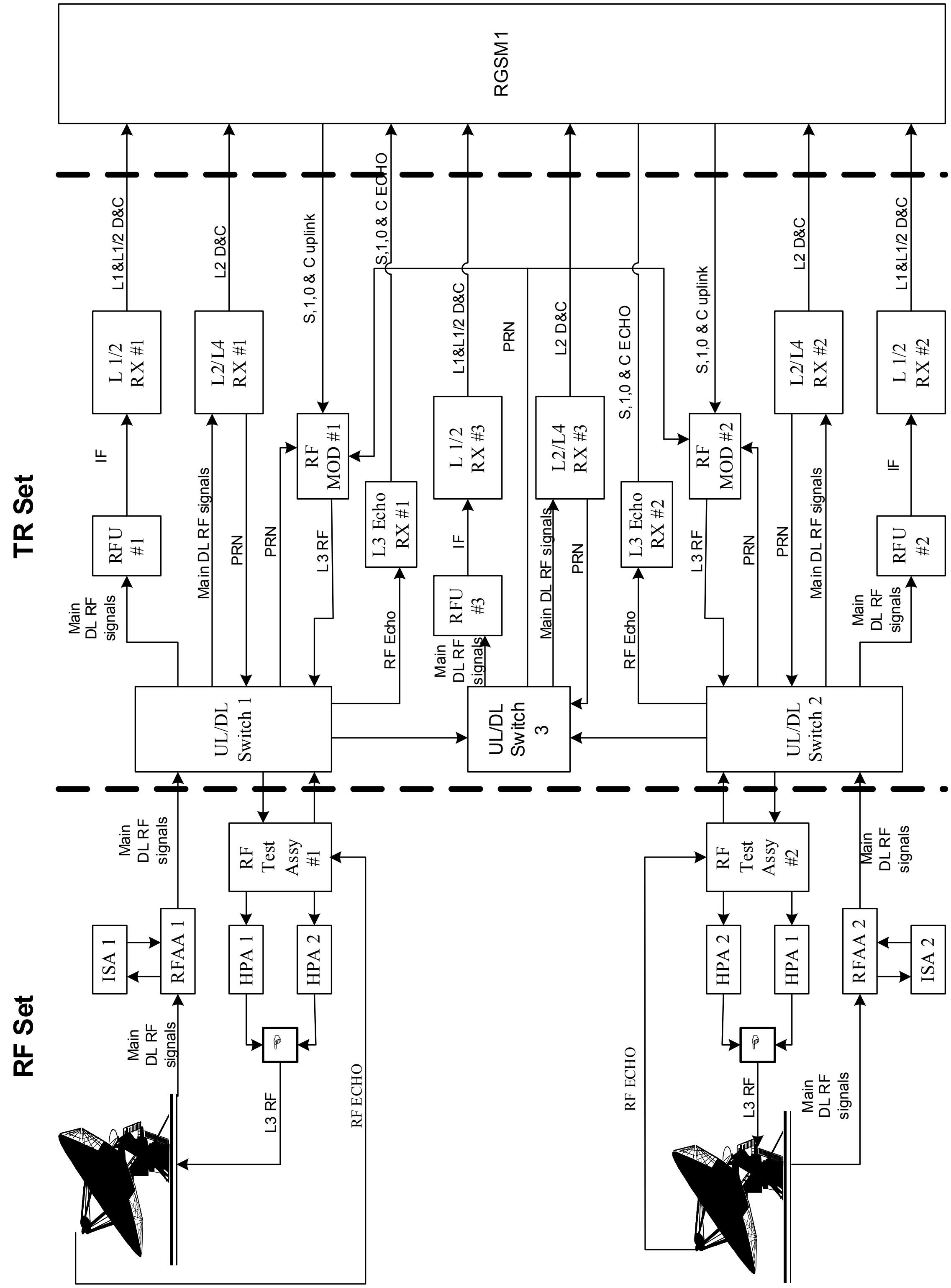
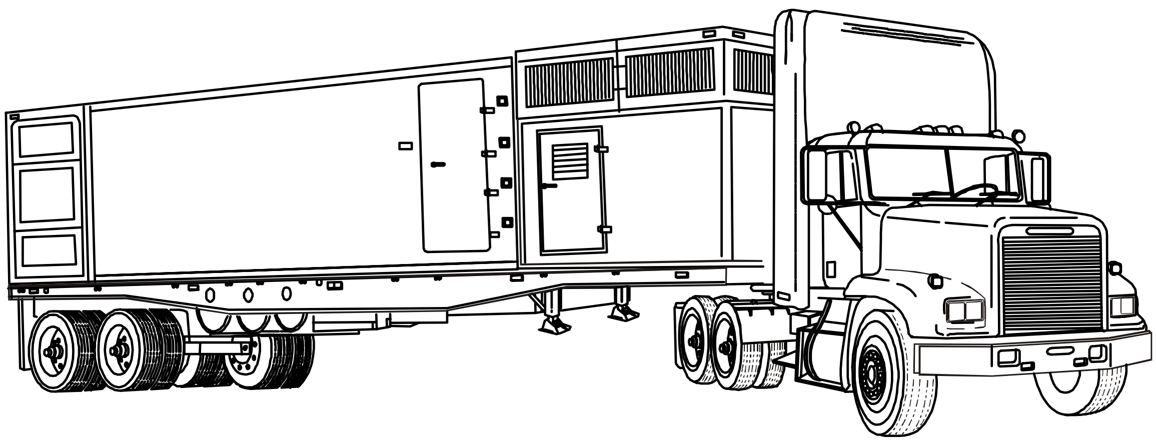


Figure 3-2, Simplified Block Diagram

Block 14, Chapter 3
Defense Support Program

Section II

MOBILE GROUND SYSTEM



Purpose

The primary mission of the Mobile Ground System (MGS) is to provide immediate worldwide missile warning, space launch and nuclear detonation detection to NORAD, unified and specified commands, in-theater commanders, the Joint Chiefs of Staff and National Command Authorities. It's capable of detecting missile launches by processing multiplexed Link 1/2 mission data from the Defense Support Program (DSP) spacecraft. The received data is processed into a Local Summary Messages (LSM). A LSM is a consolidation of launches within the satellite's field of view. A launch is detected because of the thermal image generated by a rocket motor's heat plume on the satellite's infrared (IR) sensor. A database of missile heat plume characteristics and fixed missile silo locations has been collected over the years and is used to determine missile type. The MGS can also assemble a Global Summary Messages (GSM) from Local Summary Messages (LSM). These summaries are sent to Missile Warning Center (MWC), North American Aerospace Defense Command (NORAD) at Cheyenne Mountain AFB, Colorado; Strategic Command Headquarters in Omaha, Nebraska; and the National Command Authorities in Washington DC

Typical Deployable Unit (DU) - During a typical field deployment MGS can deploy six DU's consisting of the following equipment:

1- MSQ 118 (Mission Van)
1- MSQ 180 (MILSTAR Terminal)
1- Crew Quarters Vehicle
1- Crew Support Vehicle
1- Field Spares Vehicle
1- 5500 gal Tanker Truck
3- General Support Vehicles

The MSQ-118 and the MSQ-180 are self-contained modified semi-tractor trailers, which are set up in a deployed configuration even while at home base called its Main Operating Base (MOB). It consists of a Trailer, Tractor, Power Generator Unit (PGU), Environmental Control Unit (ECU) and Operations Shelter (OPS). Physically, the MGS's mobility is limited to primary and secondary roads. It can be airlifted, via the C5A Galaxy aircraft, to support worldwide deployments. See Figure 3-3 is a drawing of the MSQ-118.

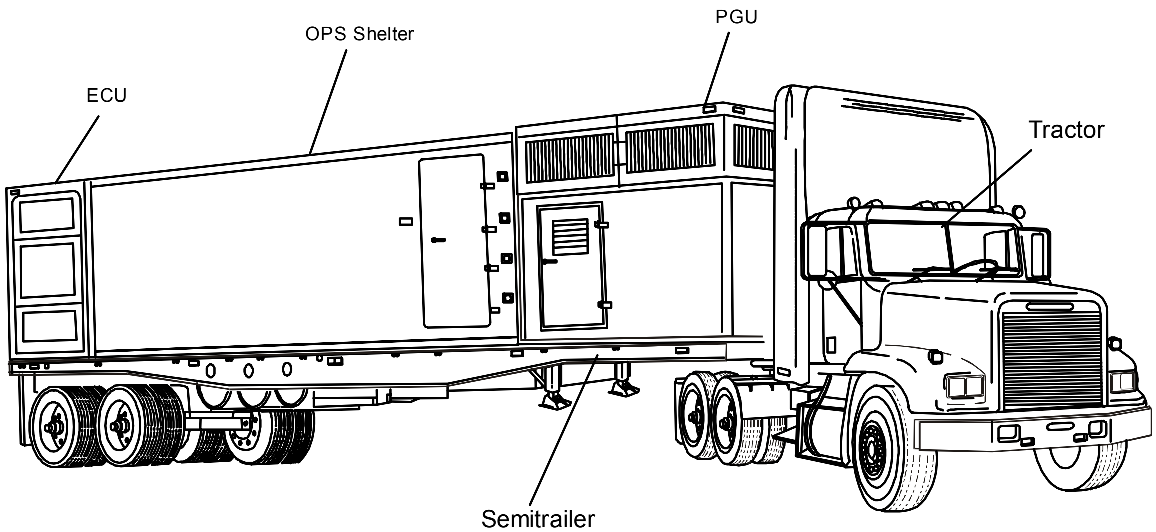


Figure 3-3, MSQ-118 System Configuration

Semi trailer - The semi trailer is a unibody frame structure. The semi trailer provides the structural strength and stiffness that support the PGU, ECU, and OPS shelter.

Tractor – The tractor is a commercial Freightliner, model FLD, used to pull the system to deployed locations.

PGU - Consists of two diesel generators, which operate separately to provide AC power source for all equipment.

ECU - Provides filtered, temperature, and humidity-controlled air to the Ops Shelter.

Major Systems of the MSQ-118

Operations Shelter –The OPS shelter contains most of the equipment associated with the MV and consists of the following subsystems:

1. Phased Array Subsystem (PASS)
2. Satellite Signals Receiver Group (SSRG)
3. Data Processing Subsystem (DPSS)
4. Timing Equipment
5. Communication Equipment

PASS - Phased Array Subsystem (PASS) – Is comprised of 18 Sub-array Networks and other support equipment. The PASS is electronically steered by the Data Processing Subsystem (DPSS) to seek out the strongest L 1/2 radio frequency (RF) signal from the DSP satellite. Pointing of the antenna is a two-part process. First, the trailer must be positioned so that the face of the array is perpendicular (+/- 5 degrees) to the downlink path from the satellite. Then, the DPSS is used to control the phasing of the antenna so the strongest signal is received. See Figure 3-4 for an illustration of the PASS.

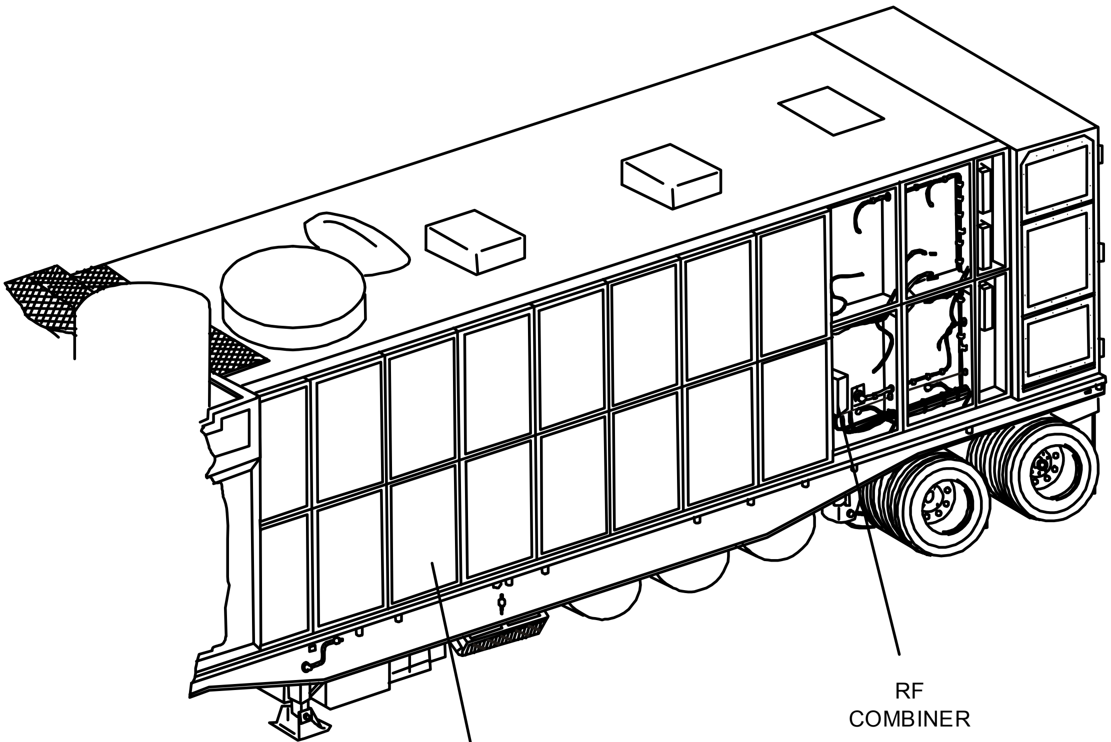


Figure 3-4, Illustration of PASS.

Subarray Network - The Subarray Network begins our discussion of the PASS. The Subarray Network is made up of 18 Subarrays that are coherently combined by the RF Feed Network into three out put signals. Each subarray contains 128 elements and a 3-bit phase shifter that is steered by either the AUTO or DIRECT commands from the DPSS. AUTO mode is used during normal operation to steer the antenna to a sky location of maximum signal strength for the satellite. DIRECT is used during testing to steer the antenna to predetermined location and is usually used during maintenance or system testing.

RF Summing Network - This system of RF summing modules and cables couples the signals from the 18 subarrays into the three signals; Channel A, Channel B, and Channel C. Each channel consists of the RF output of 6 subarrays.

RF Combiner Unit - This unit filters, amplifies and couples the input summed signals from the 3 PASS channels into four outputs; CH A, CH B, CH C, and a "Combined" output of A+B+C. These signals are fed to the Satellite Signal Receiver Group (SSRG). It also routes control, status and clock signals between the subarrays and the DPSS.

Satellite Signal Receiver Group (SSRG) - The SSRG is a one-way interface between L 1/2 and the PASS. The Link 1/2 is a 2232.5 MHz quadrature phase shift key (QPSK) transmission that is received by the PASS. It consists of the Radio Frequency Unit (RFU), a Receiver, and a Data Quality Monitor (DQM). Its operational modes are Normal, Emergency (degraded equipment or disturbed atmosphere environment), Self-Test, and Auxiliary. The SSRG also receives and processes mission data messages (MDM) and time of day (TOD) for use in the AFSATCOM II Modulation Compatibility Terminal (AMCT) communications. See figure 3-5, Simplified Block Diagram.

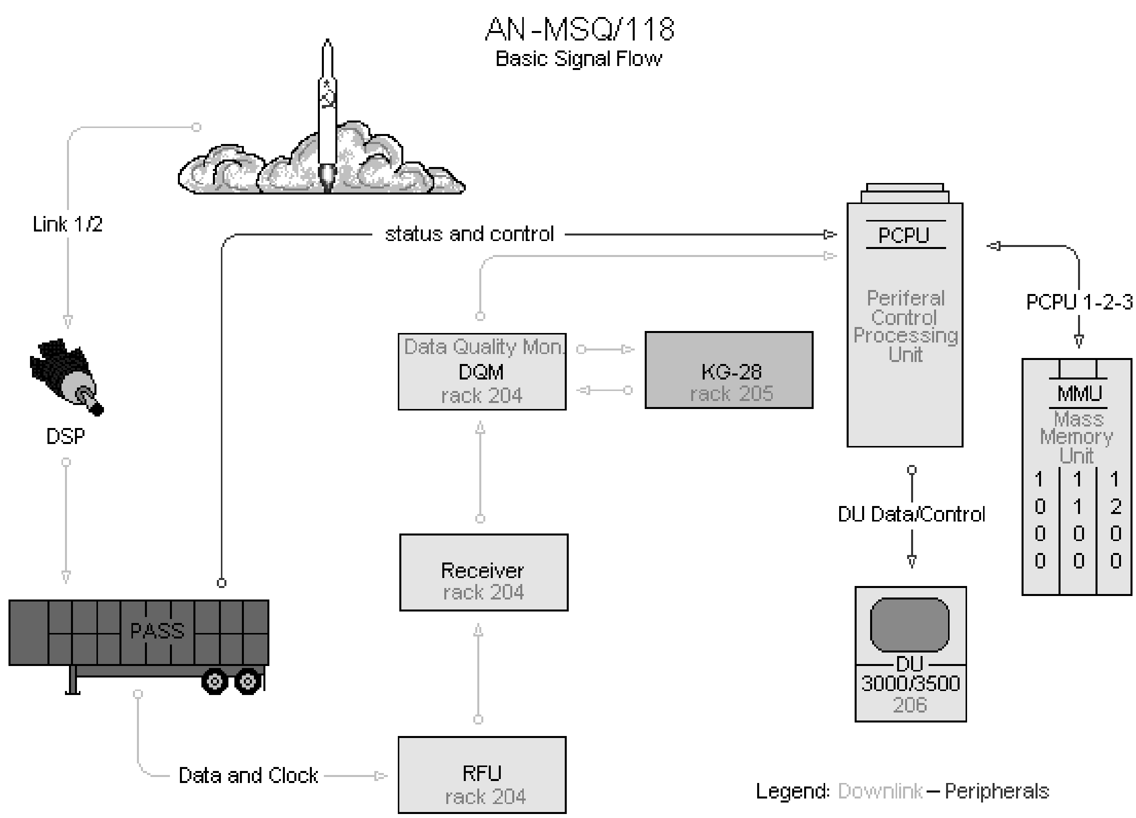


Figure 3-5, Simplified Block Diagram.

The RFU receives L 1/2 and downconverts it to a 160 Mhz intermediate frequency (IF) and passes it to the receiver. The Receiver is highly specialized and can compensate for atmospheric distortions through the use of scintillation mitigation. It corrects signal distortions due to variations in frequency, phase, amplitude, noise, and spectrum attenuation when passing through a disturbed atmosphere. It demodulates and synchronizes the IF L 1/2 signal to recover the digital L 1/2 data and clock. The DQM separates the multiplexed L 1/2 data into its primary components: L1 (local sensor data) and L2 (satellite telemetry, MDM's from other MGT's, and time of day). The DQM also determines the received data error rate and monitors data integrity. Data is then sent to the DPSS for processing and display.

Data Processing Subsystem (DPSS) - The DPSS processes L 1/2 data, provides for operator interfacing, generates, and stores LSM and GSM. It consists of seven Peripheral Control Processor Units, Mass Memory Unit (MMU), Magnetic Cartridge Tape Unit (MCTU), two Display Units and a Line Printer (LP).

The key elements of the DPSS are:

a. Peripheral Control Processor Unit (PCPU) - provides high speed data processing and peripheral control for the DPSS. PCPU 1 thru 7 interprets and executes the software instructions contained in the executive and mission computer program. The executive and mission programs provide software instructions for the PCPU string to control processing of input and output data from all peripherals and related management tasks. The primary functions of each PCPU are listed below:

1) PCPU-1 - Time-tags L1 data with time of day code and stores it in the MMU. The data is later used for Local Summary report preparation. It also controls one of the two Display Units and Line Printer.

2) PCPU-2 - This processor controls the PASS to acquire the DSP satellite.

3) PCPU-3 - Interfaces with the Mass Memory Unit and communication equipment to process Local Summary Messages (input/output) and High Speed mission data messages.

4) PCPU-4 - Interfaces with the communication equipment and DPSS to process LSM, GSM, and Composite teletype messages.

5) PCPU-5 - Has no specific function, but assists the other PCPU in task accomplishment and data handling.

6) PCPU-6 - Process Link 2 data and controls one of the two Display Units.

7) PCPU-7 - Interfaces with the AFSATCOM II Modulation Compatibility Subsystem Equipment.

b. Mass Memory Unit - The Mass Memory Unit (MMU), consists of three identical Memory Units (MU). This unit provides a nonvolatile memory storage media for DPSS. Initially the programs to operate the system are loaded into the MMU. During Operation the MMU also temporarily stores mission data.

c. Magnetic Cartridge Tape Unit – The MCTU is used to load operational and diagnostic programs from 8mm Digital Audio Tape (DAT). MCTU is use to initially load the MMU and also for logging mission data and system status during operations.

d. Display Units - provides operator control of the DPSS and communication systems using a man-machine interface via the keyboard and trackball. They are also used to run tests on equipment. On-line tests are verification routines performed during mission operations to check DPSS peripheral equipment. Off-line tests run diagnostics when a problem is suspected and uses Built-in-Test Equipment (BITE).

e. Line Printer Assembly - Provides a hardcopy of test results and error messages.

The DPSS can be initialized during a "cold-start" from data stored on a Digital Audio Tape (DAT) in the MCTU or initialized during "warmstart" from the MMU core storage. A cold-start is used during initial set up for the first time during a deployment or if there is no data in the MMU. A warmstart is used, if after initial setup. A momentarily power loss or computer lock-up (ABEND) may take the processors off-line. With magnetic core storage, programs will remain in memory even with power removed. Halted program execution is quickly reinitialized without having to reboot the system from tape. The DPSS formats L1 mission data into reports for transmission to the users, stores the data in a database for transmission to other DUs, and formats the data for display. Any available PCPU can retrieve stored reports from the MMU and prepare them for transmission. The LSM and GSM reports are formatted into a 75 b/s stream for "low speed" transmission and 4800 b/s Mission Data Message (MDM) stream for "high-speed" transmission.

Timing Equipment - Accurate time of day is critical and is needed in the precise tracking of DSP satellites. The 118 receives Universal Time Coordinated (UTC) broadcasts from Global positioning Satellites (GPS). The GPS receive send an IRIG-B signal to Time Code Generator/Translators (TCG/T's). The TCG/T's uses the IRIG-B signal to generate both 1 pulse per second (PPS) and Group Binary Time-Of-Day (GBTOD). The 1 PPS reference to be use by other equipment during operations. The GBTOD is used by the PCPU to time tagging data.

Communication Equipment - The most important requirement for the MGS to fulfill is to communicate DSP mission data to the President of the United States (POTUS), the Joint Chiefs of Staff and Strategic users (NORAD, NAOC, TACMO, ABNCCP, MCCC). The MGS can be deployed to different locations worldwide and must communicate with each other in addition to the users, or customers, through a number of different communication subsystems. An MV, or 118 van, when deployed with all its support vans is called a Deployed Unit (DU). See Figure 3-6 for Communications Systems Interfaces and Figure 3-7 for a view of a field deployment communications. The communication systems that are in the MV are:

a. **Ultra High Frequency/Line Of Sight (UHF/LOS).** - The UHF/LOS provides a secure simplex Global Summary uplink and a full-duplex voice uplink and downlink capability between the CS and an airborne user (TACMO, ABNCCP, NAOC). The UHF/LOS equipment upconverts and downconverts the UHF signal transmitted to and received from the airborne user. The GS reports are multiplexed onto any one of twelve transmit channels, the specific channel used is operator selectable. Non-secure voice is multiplexed onto a dedicated transmit channel. The GS report and voice channel frequencies are modulated onto an IF carrier that is mixed with a UHF between 225-400 MHz, amplified to 100 watts and transmitted. UHF/LOS is usually used while the MGT is deployed.

b. **Air Force Satellite Communication (AFSATCOM) via the Fleet Sat Satellite.**- The AFSATCOM is a secure UHF uplink and downlink between the 118 and a user that is active during field deployments. AFSATCOM consists of half-duplex secure 75 b/s GS data and 75 b/s TTY uplink and downlink and is FSK modulated in the 240-400 MHz band. It is used to provide worldwide secure satellite communications with the MOB and both ground and airborne users. It is currently undergoing transition to the UHF Follow On (UFO) Satellite constellation.

c. AFSATCOM II Modulation Compatibility Terminal (AMCT) via the DSP satellite.- The AMCT equipment is a full duplex interface between deployed 118s via the DSP spacecraft and consists of uplink channels 7A/7B and downlink channel 8. Links 7A/7B operate in the Q-Band, transmitting Global Summary data on Link 7A and Local Summary, TTY, and satellite commands on Link 7B. Link 8 operates in X-band and is used to track the satellite.

d. MSQ 180 MILSTAR Communication Vehicle (MCV) MILSTAR is a joint service satellite communications system that provides secure, jam resistant, worldwide communications to meet essential wartime requirements for high priority military users. The multi-satellite constellation will link command authorities with a wide variety of resources, including ships, submarines, aircraft and ground stations.

The MV and MCV are connected by an encrypted synchronous 1200 bit per second (bps) full duplex link via a cable.

The MCV allows the mission operators in the MV to send and receive teletype message over Missile Warning Command & Control Data (MWC2D) network.. Also transmit and receive LSMs and GSMs.

These communication schemes act as a primary and as a backup to each other, as equipment and environmental constraints vary, to provide mission data to the users and other DU's. A "priority" user (Airborne Command Post) may be designated to receive information from a particular MGT. This MGT is designated as the Globalizing Vehicle for the deployed network of MGT's. The non-globalizing MGT's will **not** transmit their summaries to the priority user directly because of line-of-sight limitations, but will transmit local messages via satellite to the Globalizing Vehicle instead. The Globalizing Vehicle will reformat the summaries and transmit them to the priority user.

Transmitting methods change depending on whether the MGT is at the MOB or deployed in the field. The only difference is the use of the Ground Communication Network (GCN) while at the MOB. When the 118 is at the MOB it can be connected to GCN, which is routed through the base communication center similar to a standard telephone trunk line. During field operations, the MGT uses the UHF/LOS equipment, AFSATCOM equipment, AMCT equipment and MCV for communication

MOB Deployment – The MGT can communicate through GCN or any deployable configuration.

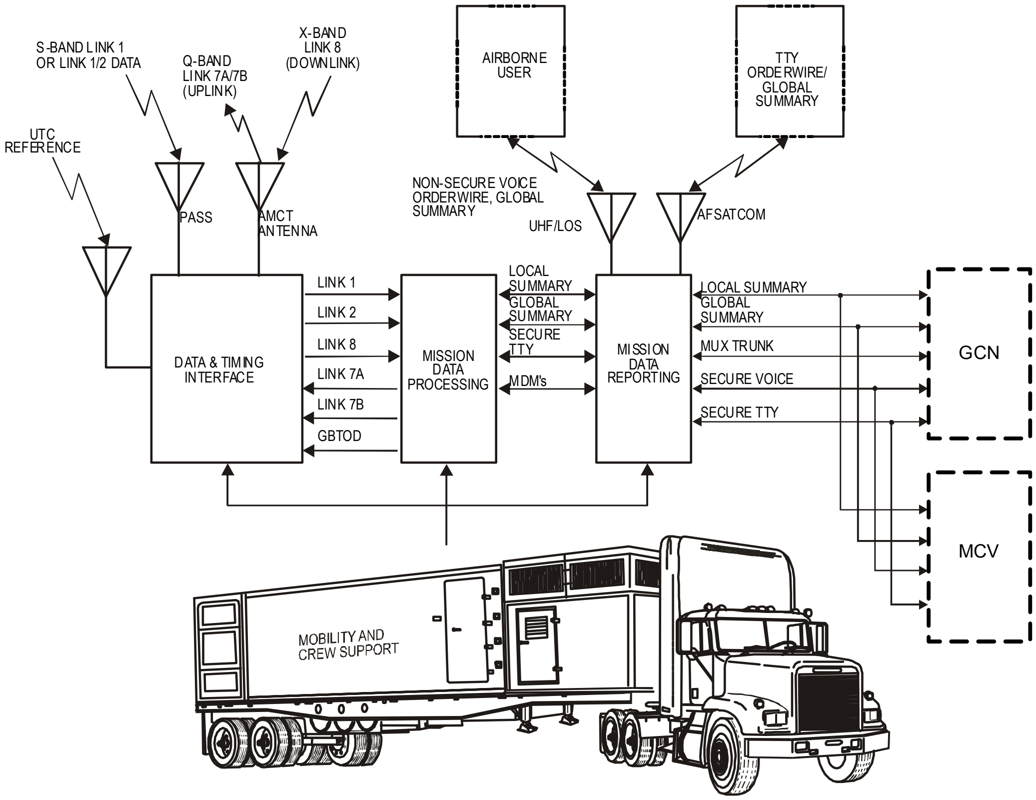


Figure 3-6. Communications Systems Interfaces

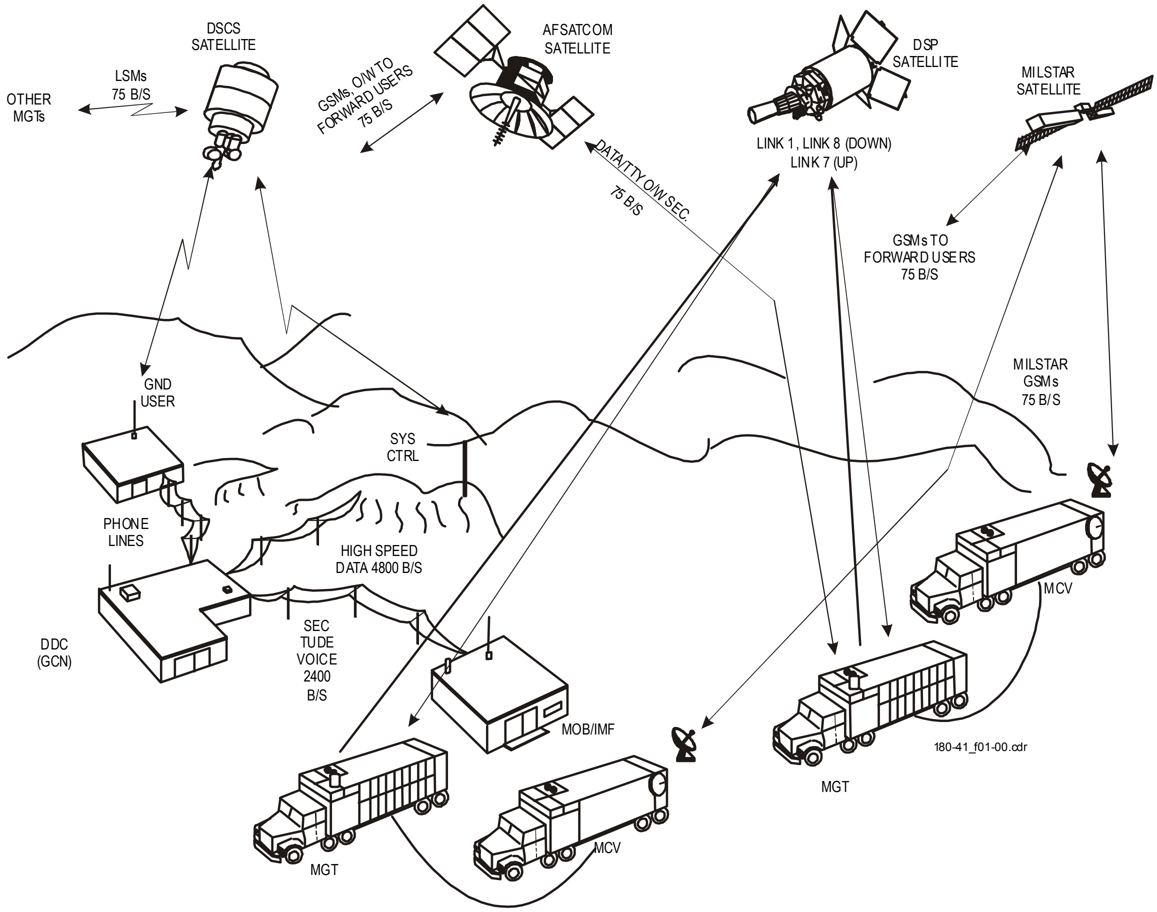


Figure 3-7. Field Deployment

SUMMARY

The MSQ-118 provides four major functions: satellite communication, mission data processing, mission data reporting, mobility, and crew support. The MGT is setup at its Main Operating Base (MOB) or in the field in a deployed configuration. It receives time via GPS to provide a UTC Binary Coded Decimal (BCD) time-of-day reference for its processors. The MGT can receive and process data from any DSP satellite within its field of view and can transmit data and satellite commands on uplink channels Link 7A and 7B. The MGT can receive Local Summary (LS) reports from other MGTs to create a Global Summary (GS). The MGT can send these reports to a wide variety of users via different communication channels. Its mobility, data processing and reporting, and communication capabilities make the MGT an indispensable tool for the Strategic Defense of North America.

Telemetry System Principles

Now we are going to discuss the Instrumentation / Telemetry portion of Block 14. There are over two hundred jobs currently in the Air Force that pertain to this. Listed below are the various assignments that a SWATS team member can be assigned to in support of R&D and OT&E.

BARKSDALE AFB

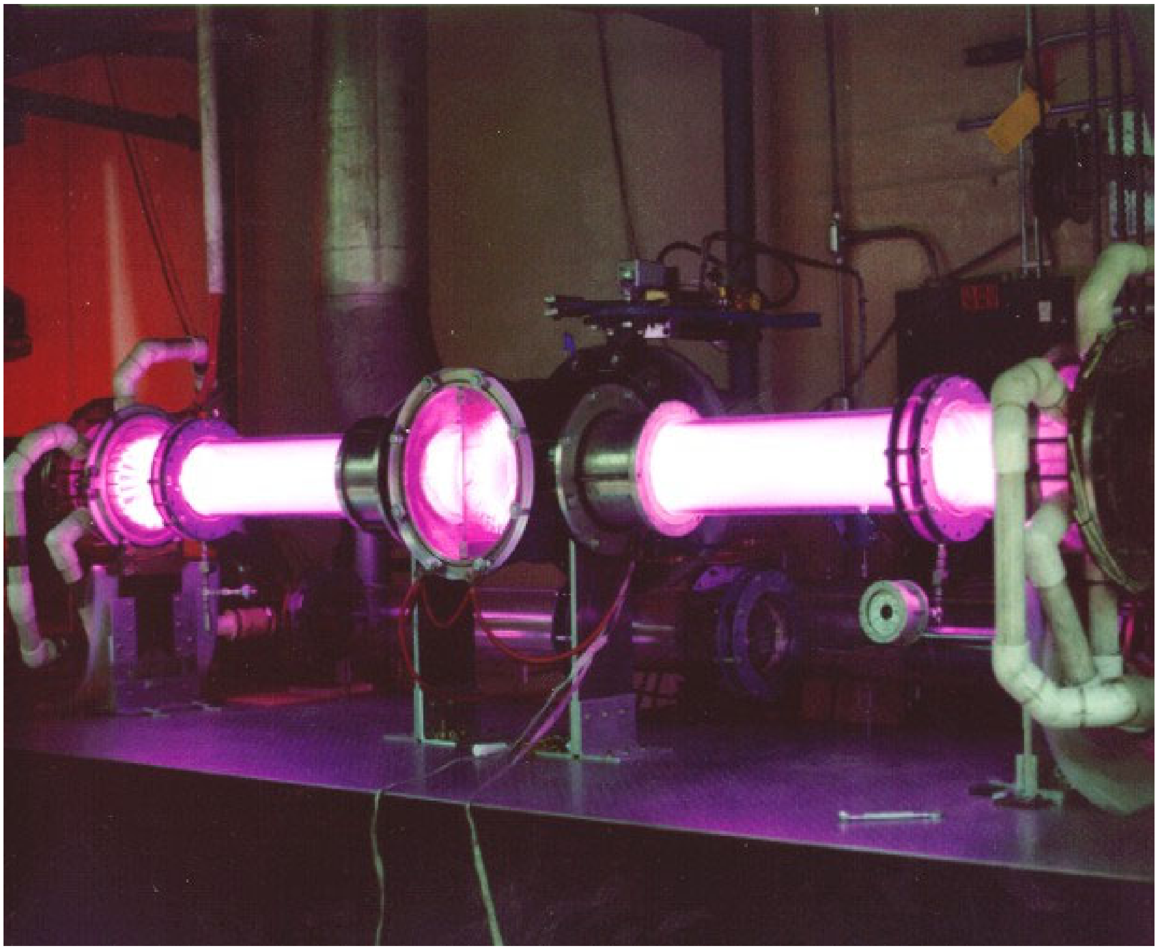
(AGM –86B Air Launched Cruise Missile Test Flight)

49TH Test Squadron

The 49th Test Squadron plans, conducts, and reports on Air Combat Command's operational Test and Evaluation (OT&E) of major airborne weapon systems which include the B-1B, B-2, and B-52 aircraft, air-launched cruise missiles, standoff missiles, and gravity weapons to determine their operational effectiveness, suitability, and maintainability. The instrumentation branch is responsible for the checkout, troubleshooting, repair, and installation of the instrumentation systems for use on OT&E and other special projects as directed.

BROOKS AFB

AIR FORCE RESEARCH LAB (Human Effectiveness Directorate)



(CO2 laser being Fired)

- Directed Energy Bioeffects Division

The mission of the Directed Energy Bioeffects Division is to predict, mitigate, and exploit the bioeffects of directed energy on Department of Defense (DoD) personnel, aerospace missions, and the environment. They recommend safety standards and provide system design specifications and conduct health and safety analyses and bioeffects validation for proposed non-lethal technologies.

- Optical Radiation Research Systems

These instrumentation systems make laser, radiometric, and photometric measurements to establish safe exposure limits for laser systems. These limits establish occupational and training standards for aircrew, maintenance personnel, and medical personnel using lasers.

EGLIN AFB

(B-1 Bomber)

16TH TEST SQUADRON

The primary mission of the SWAT element within the organization is Electronic Countermeasures (ECM) software validation for heavy bombers; B-52, B-1B, and B-2. This includes both flight test and lab/mock-up validations. Technicians use systems to instrument the aircraft with data bus collection systems, Closed Circuit TV, and beacons; post flight analysis of data and video editing; and design and build instrumentation systems.

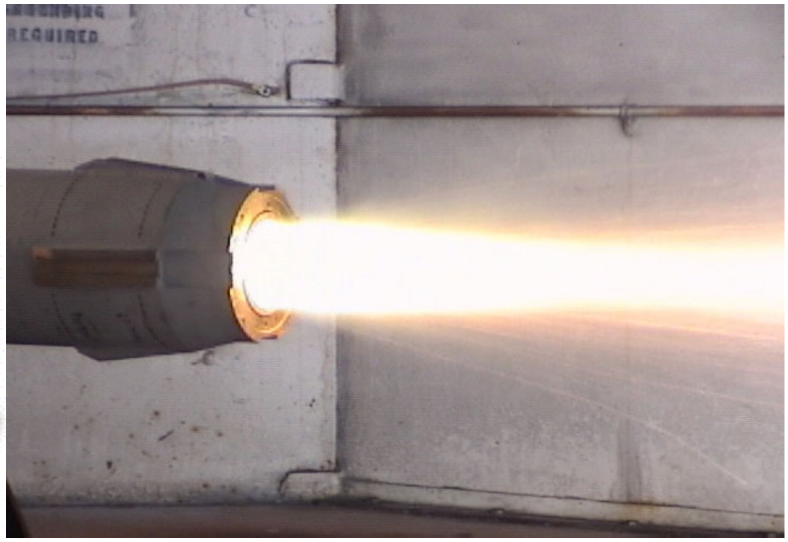
- Additional Eglin AFB Missions
Remote Target Systems
Remote Target Systems are instrumentation systems installed in land- and sea-based targets that allow for remote control.

- Robotic Explosive Ordnance Disposal Vehicles
These vehicles are remotely controlled vehicles containing a telemetry system with video used for explosive ordinance disposal. The remote vehicles are used to recover hazardous U.S. and foreign test munitions. A small cadre of technicians maintains robots used for explosive ordnance disposal remote recovery. They maintain, modify, and repair eight special purpose remote control vehicles to component level. They also install, calibrate, and repair video, telemetry systems and microwave links.

Range Instrumentation System
Test and evaluation needs the support of a range instrumentation system, which includes precision instruments for data collection, microwave systems for data transfer, and radio and land line communication networks. A centralized mission control facility, located on Eglin AFB FL, integrates these systems. A major part of the range instrumentation system focuses on capturing time-space-position-information from each test. Other essential pieces of the instrumentation system include data handling systems, threat simulator radars, telemetry systems, and communication support systems.

These systems are permanently installed ground components and can be supplemented from the ground and air as required.

HILL AFB



(Solid rocket motor test)

<u>649TH MUNITIONS SQUADRON</u> (MUNS)

The 649th MUNS provides aging and lifecycle surveillance testing to support the Air Force Explosive Safety Test Program by performing inspections, setup, temperature conditioning, environmental simulation and functional firing for components of any munitions item. The 649th MUNS accomplishes shelf/service life static test firing of all three rocket motor stages of the Minuteman Missile System as well as smaller tactical missile motors such as SRAM, Maverick, Sparrow, and Shrike. They are responsible for the installation, calibration, operation, and maintenance of instrumentation equipment used in the acquisition of the following parameters: acceleration levels, chamber pressure, ignition delay, temperature, and thrust or other special instrumentation required by project engineers. Propagation testing is accomplished at the Oasis complex located at the geographically separated Utah Test and Training Range.

KIRTLAND AFB

(Artist rendition of Airborne Laser)

AIR FORCE RESEARCH LABORATORY

The laboratory is charged with furthering research and development in space and missile systems, geophysics, directed energy, and advanced weapons concepts. It concentrates its research in six technical areas: geophysics, propulsion, space and missiles technology, lasers and imaging, advanced weapons and survivability, and space experiments. The laboratory also has detachments at Edwards AFB and Hanscom AFB.

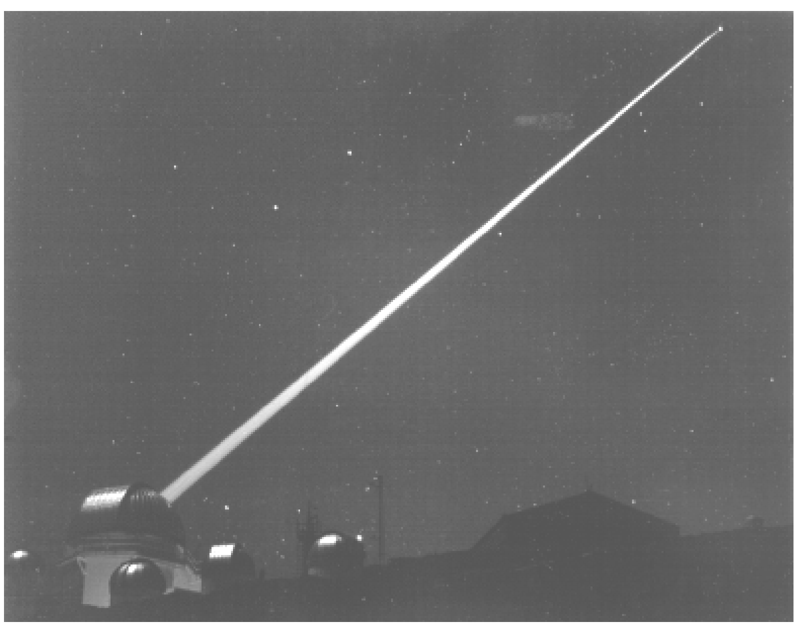
- Directed Energy Directorate

The Directed Energy Directorate (DE) of the Air Force Research Laboratory is the DOD's center of expertise for lasers, high-energy microwaves, and other directed energy technologies. The directorate conducts research into a variety of energies that might be transformed into future weapons systems.

- Starfire Optical Range

Starfire Optical Range systems are laser, optic, and telescopic systems that are instrumental in gathering data on atmospheric effects, and using adaptive optics and other techniques. The technologies developed at this site aided the development of airborne laser systems.

(Aerial Photo of Starfire Optical Range)



(Starfire Test Firing)

DEFENSE THREAT REDUCTION AGENCY (DTRA)

Field Command Defense Threat Reduction Agency is a joint service organization. The Defense Threat Reduction Agency safeguards America and its allies from weapons of mass destruction (chemical, biological, radiological, nuclear, and high explosives) by reducing the present threat and preparing for the future threat. DTRA is responsible to the Director, DTRA; to the Chairman, JCS; and to the Under Secretary of Defense for Acquisition.

TYNDALL AFB

DET 1, 85TH TEST AND EVALUATION SQUADRON

Det 1, 85 TES plans, conducts, and reports on operational test and evaluation (OT&E) of fighter radars and their interoperability with various weapons systems. These efforts include hardware and software evaluations of aircraft fire control systems and missile systems, as well as electronic attack (EA) and electronic protection (EP) systems, techniques, and applications. Det 1, 85 TES also provides input and assistance to HQ USAF, ACC, Air Force Operational Test and Evaluation Center, and Air Force Materiel Command in the development of test plans, conduct of test projects, collection of test data, and production of final test and evaluation reports as directed by HQ ACC. The Integrated Avionics Test Facility (IATF) supports this mission in various ways. The IATF's primary objective is to improve the combat capability, reliability, and lethality of Air Force weapon systems through operationally realistic testing. Missions are performed through ground test, flight test, ground-based jammer testing, and various combinations of these techniques. The IATF's primary mission is to perform force development evaluations on the operational flight programs (OFP) of the F-15 and F-16 fire control radar systems. This includes experimental changes to the OFPs as well as modifications to fielded OFPs. Additional responsibilities and capabilities include the following: Perform OFP OT&E and operational utility evaluations of F-15 and F-16 radars with the AIM-120A/B/C advanced medium range air-to-air missile (AMRAAM). Identify radar system maintenance deficiencies and develop work-around solutions. Support advanced EA and EP system development and evaluation. Provide resident Air Force technical expertise on ACC radar and missile systems. Support other electronic warfare projects from Air Force, DOD, and various external customers with technical assistance or specialized hardware.

83RD FIGHTER WEAPONS SQUADRON (FWS)

The 83rd FWS evaluates the overall effectiveness of fully integrated air-to-air (A-A) weapons systems in realistic scenarios IAW USAF Directive 79-3, Air-To-Air Weapon System Evaluation Program (WSEP). It provides operational control and maintenance support for the exercise of the total A-A weapons systems, including aircraft, weapons delivery systems, weapons, air crew, and maintenance personnel. It collects, analyzes, and reports on all armament firings and attempts by tactical and strategic fighter aircraft. The flight maintains the ACC WSEP database to support Air Force decision-makers regarding the current capability of tactical and strategic A-A weapons systems and provides fault analysis of current weapons systems, makes appropriate recommendations for hardware/procedural improvements, and validates proposed enhancements. The FWS provides operational support to deployed units under non-WSEP programs and investigates missile envelopes, target scoring, and effects of electronic counter measures in a realistic operational scenario. It manages support of FWIC live-fire syllabus and conducts William Tell A-A weapons meet and determines future firing requirements and analysis capabilities, and initiator identification of material/quality design deficiencies found during firing and post data analysis. The squadron insures collection of telemetry data via a ground site or two modified DeHavilland aircraft. Unit ground and airborne telemetry sites also provide additional data acquisition support to all users (to include Navy, Army and foreign nations) of the Eglin Gulf Test Range. The sites provide information on target scoring, electronic countermeasures, and armament data on different A-A, air-to-ground (A-G), and surface-to-air weapons testing.

- INSTRUMENTATION SYSTEMS

A large portion of jobs within the squadron involves the operation of telemetry hardware located at a ground station and also within two aircraft assigned to the group. The equipment at the ground site includes two 8 foot receiving antennas, receivers, decommutation equipment, bit synchs, discriminators, filters, magnetic tape recorders, stripchart recorders, computers, and test equipment. The prime job of instrumentation technicians is to ensure the optimum collection of telemetry data to provide to analysts the capability to analyze missile system performance. Another major part of the job here includes performing periodic calibrations to individual pieces of hardware and also overall system checkout of the ground site. Most typical data formats are PCM/FM, PCM/FM/FM and PAM/FM based and currently go up 1.8MB. The site collects TM data in the L-Band and upper/lower S-Band frequency range. The airborne telemetry system which comprises a 30 foot long S-Band phased array mounted on the side of modified DeHavilland Dash-8 commercial airframe is operated by military personnel but maintained by contractors. The system has no data processing equipment but is comprised of receivers, a data distribution system, recorders, transmitters, and test equipment. The prime job of these technicians is also to ensure optimum collection of telemetry data and to document system performance, and to work with contractors in identifying deficiencies and providing recommendations.

UNITED STATES AIR FORCE ACADEMY

The personnel assigned to this special duty support engineering courses with labs, equipment, and technical advice. They manage machine shop/electronic lab for cadets to build projects, build rockets for the Astronautics class with various payloads, and maintain and calibrate analog and digital computers for controls classes. They also assist in research for students/instructors in robotics, and space experiments dealing with control systems (satellites).

(Minuteman III FDE Preparation)

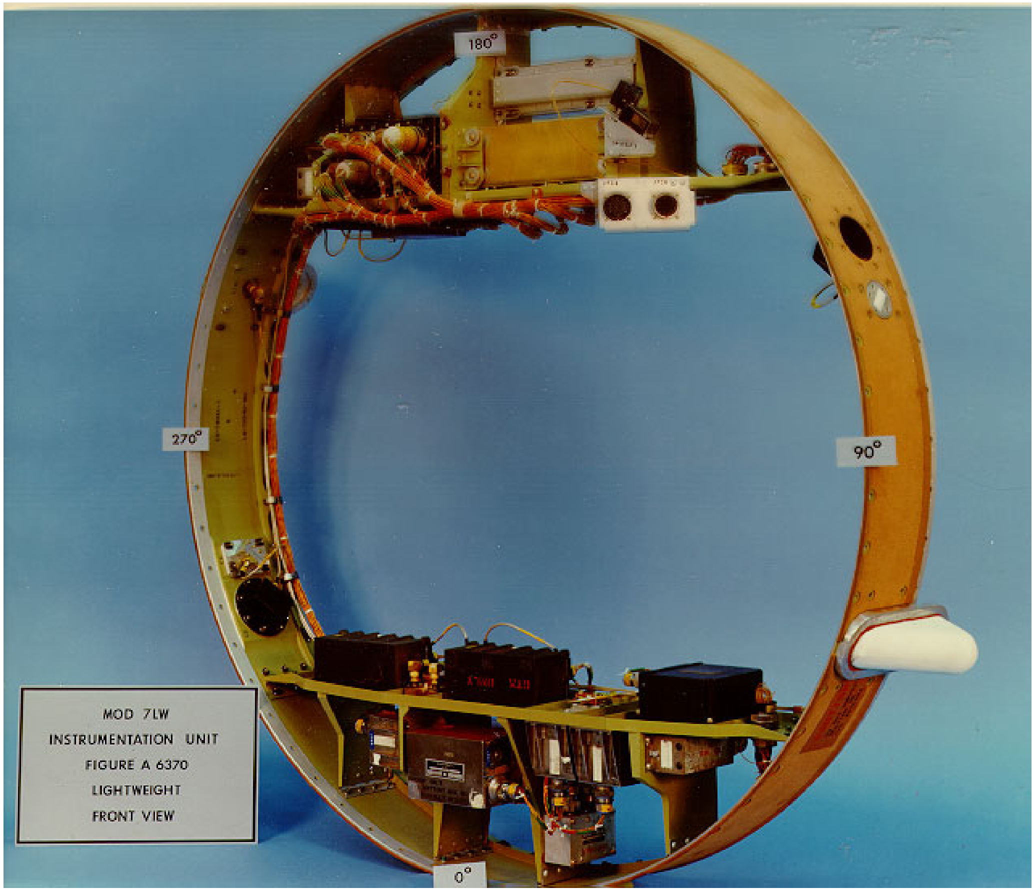
576TH TEST SQUADRON

SWATS technicians at Vandenberg process and install airborne and ground support equipment in support of Force Development Evaluation (FDE) Minuteman III and Peacekeeper ICBMs. The airborne equipment includes Telemetry, Command Destruct, Flight Tracking, and power subassemblies. They also gather and analyze real-time and post mission data received from the telemetry packages install on the ICBMs. This data is then put into post-flight reports that are used to verify the readiness of the standing ICBM alert force located at the Northern-tier bases. There are three main areas concerned with the Satellite, Wideband, and Telemetry (SWAT) missions at Vandenberg: Minuteman Instrumentation, Peacekeeper Instrumentation, and the Launch Analysis Group (LAG).

(Minuteman III Launch)

- MINUTEMAN INSTRUMENTATION

Minuteman Instrumentation consists of two sections, airborne and ground. The airborne side processes the MOD 7 instrumentation wafer for installation onto the top of the guidance section. Processing includes tolerance checks and system validation of the telemetry, C-band (Flight Tracking), power and command destruct wafer systems. The ground side performs checkout and operation of the Launch Support System, used to monitor and control the wafer during the pre-launch process, as well as transferring the wafer to missile battery power minutes before launch.



PEACEKEEPER INSTRUMENTATION

The role of Peacekeeper Instrumentation is very similar to that of Minuteman Instrumentation. One of the main differences is the configuration of the telemetry package. The Telemetry package consists of a assembly called a Instrumentation Flight Safety System Truss Assembly or ITA for short. This ITA is roughly the equivalent of the wafer, but it sits in place of a Mark 21 Reentry vehicle (RV) warhead on what would be position 10 of the Post Boost Vehicle of the ICBM. This Telemetry Package is used on FDE Flights for Peacekeeper ICBM. There is also a Launch Support System for monitor and control and power transfer of the truss assembly during the pre-launch process.

(Peacekeeper Post Boost Vehicle – ITA installed)

- LAUNCH ANALYSIS GROUP

This section provides real-time and post-launch telemetry analysis for Minuteman and Peacekeeper Follow-On Test and Evaluation launches. They interface ICBM launch data needs with the western Test Range to support Ogden ALC, TRW, and other data users. It is a combined section manned by personnel with prior Minuteman/Peacekeeper launch experience in the Grades of SSgt through Lt Col. This section also comprises the Launch Countdown Team for all ICBM test Launches. SWAT technicians may apply for LAG after they demonstrate the experience and responsibility necessary to perform the required duties. They perform the data gathering and analysis of the missile status and telemetry information before, during, and after launch. LAG members monitor the performance of the entire missile and supporting Range systems through the wafer and truss, perform investigations into any missile anomalies when they occur, and determine the cause. LAG members may also serve in the role of Launch Systems Advisor to the Launch Director/30th Space Wing Commander.

WHITEMAN AFB

72ND TEST AND EVALUATION SQUADRON (TES)

(B-2 Stealth Bomber)

The mission of the 72nd TES is to support the force development test and evaluation missions of the B-2 Advanced Technology Bomber. In addition, the 72nd TES develops and employs the following specialized instrumentation pallets in support of various combat exercises.

- AIRBORNE INSTRUMENTATION SECTION (AIS)
AIS installs specialized instrumentation pallets on-board the B-2 bomber providing data collection and telemetry downlinks to the range ground station. The specialized systems include the airborne instrumentation system, range instrumentation system and the weapons re-radiation system. These systems are unique and only used on the B-2. These pallets comprise subsystems that include aircraft bus recording, video and audio recording, weapon recording, telemetry downlink and re-radiation, GPS, and Inter-Range Instrumentation Group (IRIG) time. Airborne Instrumentation System (AIS) The original instrumentation system designed for the B-2. The system is hard-wired into the aircraft and records bus data and TSPI onto an airborne recorder, and audio/video data on 8mm (Hi-8) videocassettes.

Now that we have given you a general overview into the various Instrumentation /Telemetry positions let's discuss the Test Range Mission

Block 14, Chapter 4
TEST RANGE MISSION SYSTEMS

INTRODUCTION

SATCOM, Wideband, and Telemetry Systems (SWATS) is a diverse career field. Research and Development (R&D) and operational test and evaluation (OT&E) environments comprise a small portion of the career field. Their function is to support instrumentation and telemetry systems.

RESEARCH AND DEVELOPMENT

Definition of Research and Development, in its broadest terms, is the investigation of a theory or process. It also relates to the analysis of improving the effectiveness or advancement of a current process. The Department of Defense (DOD) researches and develops many of its own weapon systems. Some of the systems under research and development today may not enter the Air Force inventory for years. Two examples of R&D that technicians are doing in our career field are development of lasers and of new applications for laser technology at Kirtland AFB, NM and Space and Missile testing at Vandenberg AFB, CA.

With this in mind, the SWATS apprentice supporting R&D may construct, modify, and test data collection, communication, and processing systems; this also includes all support equipment. By improving our data collection and processing techniques, we are able to provide accurate, precise data to engineers who play a vital role in the procurement of weapons systems for the DOD.

SWATS technicians assist engineers with the development of a concept that may develop from a rough draft on scratch paper into a formal working process. A prototype piece of equipment (may be a new weapon system, etc…) is developed from this initial stage. Journeymen provide support for collecting performance data on the prototype's development. Once the prototype has been fully tested according to design plans, performance reports are published that explains the development, performance, and suggested improvements for the system. Working hand and hand with the research and development effort is the improvement of data collection systems. SWATS personnel are continually working with engineers to improve data collection, communication, and data reduction systems. *Data collection* refers to the methods and equipment used to sample and process different kinds of information. *Communication* refers to the methods and equipment used to transfer information. *Data reduction* refers to the methods and equipment used to process and present information to the user.

With this in mind, SWATS technicians supporting research and development may construct, modify, and test data collection, communication, and reduction systems; this also includes all support equipment. By improving our data collection and reduction techniques, we are able to provide accurate, precise data to engineers who play a vital role in the procurement of weapons systems for the DOD. So as you can see your role as a SWATS technician is pivotal to the overall success or failure of future weapon systems.

PROTOTYPE DEVELOPMENT

Air Force technicians assist engineers with the development of a concept, which may be in rough draft on scratch paper, into a formal working process. From this initial stage, a prototype device is developed. The technician may also provide support for the collection of performance data on the prototype's development. Once the prototype has been fully tested according to design plans, performance reports are published explaining the development, performance, and suggested improvements for the system.

TEST AND EVALUATION

Now that we have a understanding of R/D let's discuss Test and Evaluation (T&E). The Definition of "Test" is a program, procedure or process to obtain, verify, or provide data for determining the degree to which a system (or subsystem) meets, exceeds, or fails to meet it's stated objectives. The definition of "Evaluation" is the review, analysis, and assessment of data obtained from testing or other sources to create useful information for decision makers.

Purpose of T&E is three fold. First it provides Technical Performance data to Weapon System developers. Second it provides Operational effectiveness and suitability to the Decision Authorities. Thirdly, it provides System Performance data to the Operational Forces, i.e. the Warfighter.

There are two main types of T&E. The First type is Developmental Test and Evaluation (DT&E). The second type is Operational Test and Evaluation (OT&E).

DEVELOPMENTAL TEST AND EVALUATION

The main purpose for DT&E is to demonstrate engineering design and development is complete. An additional purpose is to confirm the system performs as required and is ready for field testing. Typically DT&E is conducted in the Laboratory, factory, and proving ground. It is performed by the developer(usually a contractor), in a controlled Environment. After a system has made it through DT&E it will typically move on to Operational Test and Evaluation.

OPERATIONAL TEST AND EVALUATION

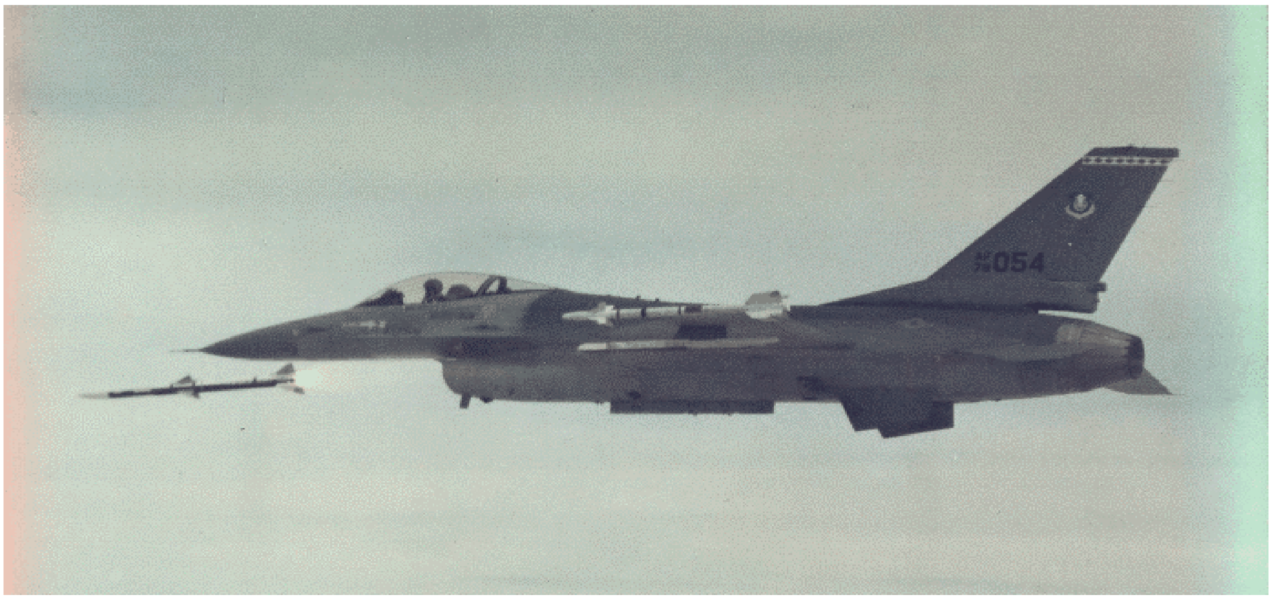
operational Test and Evaluation (OT&E) *Definition is* a process used to evaluate the performance of a system in the most realistic operational environment. This type of testing uses personnel with the same skills as those who will operate, maintain, and support the system when fielded. Operational test and evaluation starts at concept and continues throughout the life cycle of the system. Operational test and evaluation is not limited exclusively to the system; operators, support equipment, and maintenance techniques are also evaluated in this process. Some examples of OT&E are cruise and ballistic missile subsystem tests with live launches, explosive propagation and munitions tests, and guidance system tests utilizing a rocket sled on a test track.

SWATS technicians also serve an important role in the operational test and evaluation of a wide array of Air Force equipment. This equipment range varies from missiles and gravity bomb testing to airborne electronic countermeasure device performance.
Your responsibilities could entail constructing, operating, and maintaining data collection, data reduction, and communication systems that test and evaluate the performance of DOD weapons systems.

TYPES OF OT&E

There are several types of OT&E, some of these types include:

- Initial Operational Test and Evaluation – Testing that is accomplished before full rate production by the manufacturer commences.
- Follow-on Operational test and Evaluation – Verifies corrections made after IOT&E.
- Force Development Evaluation – Performed after full rate production decision or operational acceptance. Ensures the equipment meets mission requirements throughout its life cycle.



Block 14, Chapter 5
TEST RANGE ORGANIZATION

RANGE COMMANDERS COUNCIL

HISTORY OF RCC

By 1950, the United States had established three major test ranges: the White Sands Proving Ground, New Mexico; the Naval Air Missile Test Center, Point Mugu, California; and the Long Range Proving Ground on the east coast of Florida. The commanders of these three ranges, recognizing that they had many areas of mutual interest, decided to meet and discuss ways in which they could assist each other in solving their common problems.

At that time, the instruments used for the measurement of a missile's performance and flight path were quite primitive compared with today's equipment. For example, the radar was a modified version of old World War II equipment, which was used by the Germans at Peenemunde and brought to this country along with captured V-2 rockets.

It is easy to visualize some of the problems faced by range commanders trying to meet the test support needs of that day with such limited instrumentation resources. At their first meeting in August 1951, the “Range Commanders Conference” (RCC) was formed. The commanders quickly realized many range problems involving instrumentation would have to be resolved at the working level by qualified engineers and technical specialists. As a result, they agreed to have these representatives meet on a regular basis, which resulted in the establishment of the “Inter-Range Instrumentation Group” (IRIG). Later, the RCC set up other specialized groups to deal with problems such as range safety, range operations, and documentation. As time progressed, many members were providing multiple representations on each RCC group.

In 1970, several of the commanders expressed concern about the proliferation of the RCC substructure and the increase in resource expenditure. As a result, the commanders directed that the RCC organization be restructured and streamlined so that the original RCC objectives could be accomplished more efficiently. The new organization was described in detail in an ORGANIZATION AND POLICY (O&P) document, approved by the commanders in May 1971. In the reorganization, a number of the old specialized groups were restructured and merged. IRIG ceased to exist as an organization. Because of its international recognition, the acronym “IRIG” was retained and is still used on certain standards published by the RCC.

Several additional changes have taken place since the original Range Commanders Conference (RCC) was established. One is a name change to Range Commanders Council. Generally the majority of all test ranges fall under the preview of the Range Commanders Council (RCC).
The RCC structure consists of the Range Commanders, Executive Committee (EC), standing and ad hoc groups as may be established, and the Secretariat.

THE ORGANIZATION OF THE RCC

The RCC is comprised of the Range Commanders, the Executive Committee (EC), the Secretariat, and Standing Groups. Ad Hoc Groups may be established as necessary. The organizational structure of the RCC is designed to permit maximum control by the commanders, while providing for the flexible and efficient response to both long-range needs and quick-response situations.

The **Range Commanders** are not directly involved in the day-to-day activities of the RCC. The commander of each member range appoints one representative to the RCC Executive Committee. This representative is delegated the authority of his/her commander in all matters pertaining to the RCC. Each commander may appoint a technical representative to assist the executive committee member in carrying out his/her duties.

The **Executive Committee** administers the Ad Hoc and Standing Groups and assists the range commanders in other RCC matters. The committee elects its own chairman and vice-chairman, each to serve for a 2-year period. In addition, all standards must be approved by the executive committee.

The office of the **RCC Secretariat** is located at White Sands Missile Range. The Secretariat is responsible for the preparation, review, editing, processing, printing and distribution of minutes and documents, and maintenance of the historical records and files. It also effects coordination in the formulation of inter-range policy, operational procedures, standards, documentation, meeting and conference arrangements, and information exchange.

The **RCC Standing Groups** are the primary means of exchanging technical and operational information and coordinating and standardizing systems, techniques, methods, and procedures among RCC participants. The groups also are the focal points for the development, procurement and exchange of technical systems and equipment.

These groups perform tasks directed by the Executive Committee. They also exchange information on common range technical and operational problems, recommend standards for instrumentation systems and equipment, and coordinate development and procurement of systems and equipment. They coordinate and integrate long-term range capability research and development planning. The members of these groups are selected for technical proficiency in the required scientific disciplines. The following list gives a brief description of each standing group**:**

1. The Range Safety Group is responsible for *all matters relating to safety*. These include but are not limited to flight safety, laser operations, RF hazards, hazardous substance storage, infrared operations, and explosive component testing.
2. The Documentation Group reviews and evaluates existing and proposed *documentation systems*. They recommend to the EC for consideration, new or revised documentation systems and methods for their time-phase introduction.

3. The Telecommunications Group deals with *communications*, but also *range timing* and *synchronization* systems, voice, data and video transmission and recording systems, radio command and control systems, and *command destruct* systems.

4. The Frequency Management Group studies and recommends solutions to *spectrum-utilization* problems. More importantly, they advise other working groups regarding transmitter and receiver characteristics to ensure minimum interference between instrumentation and other devices emanating or receiving electromagnetic energy.

5. The Meteorology Group emphasizes improving the capability to define the effects of *astrogeophysical* parameters on marine, missile and space systems, and it seeks to better the instrumentation and techniques used to measure and predict these effects.

6. The Optical Systems Group deals with optical and *electro-optical instrumentation* systems including those using photographic or magnetic tape as the information recording medium. These systems, which may work in the ultraviolet, visible or infrared portion of the electromagnetic spectrum, are used to provide engineering surveillance and acquire trajectory, altitude, and spectrometric data.

7. The Underwater Systems Group explores the technology of *underwater tracking*, underwater recovery, and environmental data systems designed to function in the ocean.

8. The Joint Range Instrumentation Accuracy Improvement Group operates under a general charter to study and make recommendations for improvements in methods for *instrumentation performance* analysis, calibration, and evaluation procedures.

9. The Electronic Trajectory Measurements Group addresses all aspects of radar, system scorers, and altimeters used to obtain *space position measurements* and such equipment as transponders, infrared sensors, television, lasers, masers, nuclear devices, and computers which are required to enhance the capabilities of these measurement systems.

10. The Data Reduction and Computer Group oversees all aspects of *data reduction* and computing including *demultiplexing*, decoding, digitizing, translating, recording and display equipment, analysis and computational techniques, and software.

11. The Telemetry Group is concerned with such *data acquisition* equipment as airborne sensing devices and modulation and *multiplexing* equipment. The group is also responsible for writing and updating the Telemetry Standards Document and a series of telemetry system test procedures.

12. Ad Hoc Groups are established by the Range Commanders or the EC to address selected *short-term* and interdisciplinary problems of particular concern to the RCC member ranges. Hence, the name Ad Hoc, which means: a special, one-time thing.

The Range Commanders Council is dedicated to serving the technical and operational needs of U.S. test, training, and operational ranges.
The responsibilities and relationships of the RCC are to proactively share insights and products with various services and DOD organizations

The RCC provides a framework that allows for the following:

- Common needs are identified, and common solutions are sought

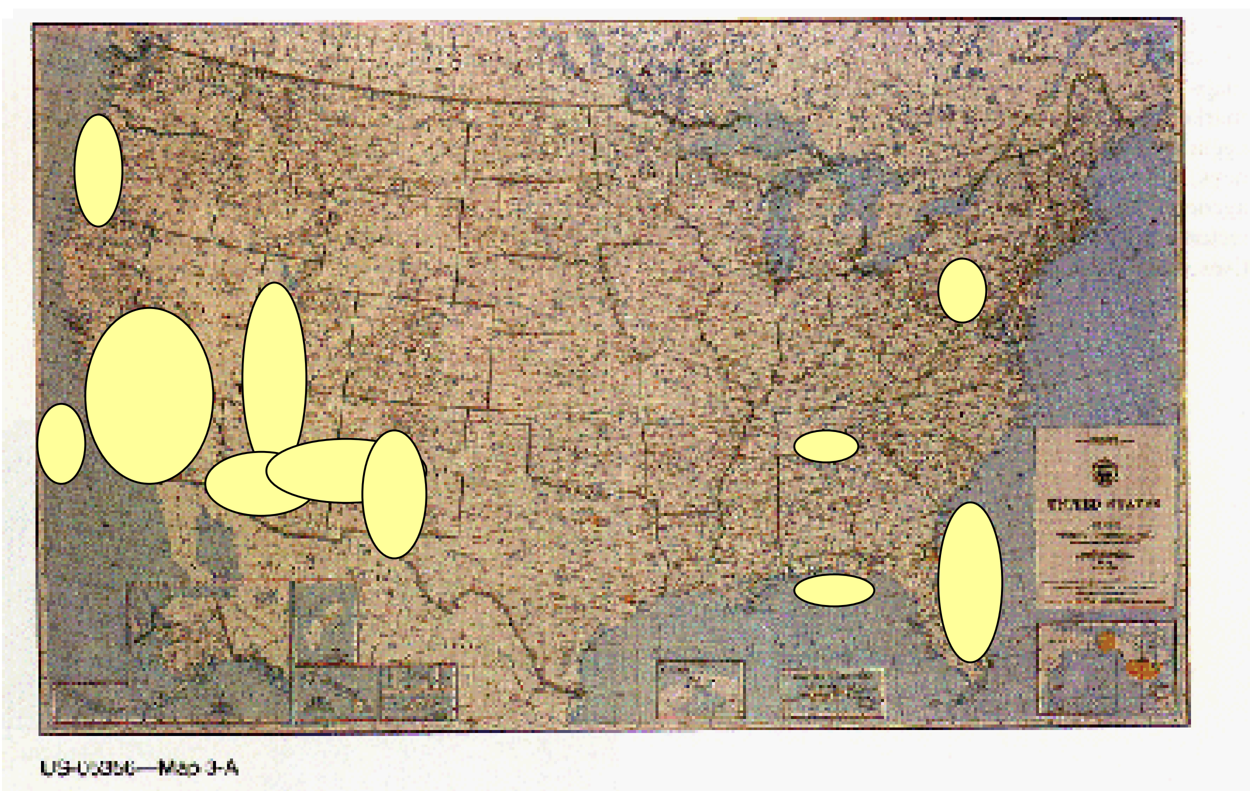
- Technical standards are established and disseminated
- Joint procurement opportunities are explored
- Technical and equipment exchanges are facilitated
- Advanced concepts and technical innovations are assessed, and potential applications are identified

The Range Commanders Council was organized to preserve and enhance the efficiency and effectiveness of member ranges, thereby increasing their research and development, operational test and evaluation, and training and readiness capabilities.

APPLICABLE RANGE STANDARDS

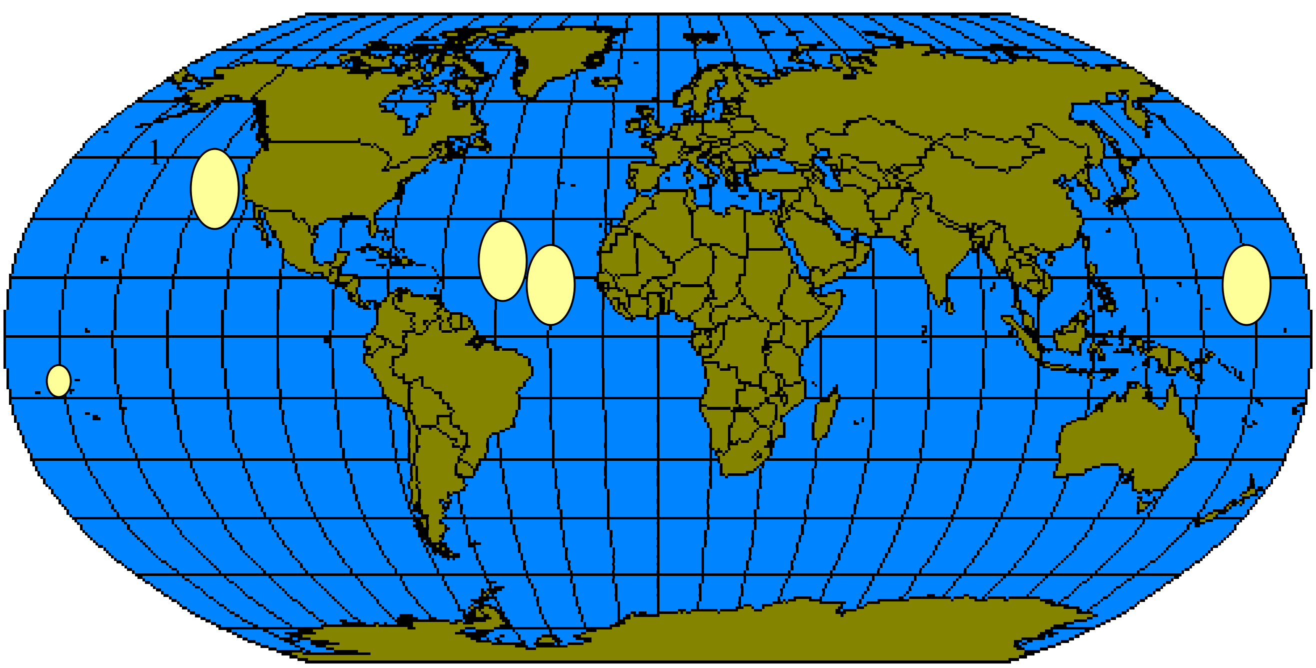
Typically as a SWATS technician if you hear the phrase "Range Standards" it refers to any standard imposed on vehicle or weapon system for a specific Test Range. There are numerous Test Ranges across the CONUS and some overseas. Figure 5-1 shows some of the CONUS test ranges. Figure 5-2 shows some of the overseas test ranges.
Range standards would include the following:

- Test methods and procedures
- Required technical and special reports
- Catalogs, guides, and glossaries



(Fig 5-1, general locations of Military Test Ranges)

Robinson projection



(Fig 5-2, Overseas Test Ranges)

TEST RANGE FUNCTIONS

Now that you have an idea of what the test range mission is, we can explore the different capabilities of a typical military test range and then define the systems that help us perform a test. The term "*range"* includes test centers and laboratories, as well as the conventional range. The conventional range consists of broad land, sea, and air spaces used for the purpose of testing aircraft, missiles, bombs, propulsion systems, navigation systems, electronic warfare systems, and any number of other systems. It is made up of people, equipment, and an area necessary for conducting safe and efficient testing.
A test range requires the skills of a wide variety of people, from machinists and electronic technicians to engineers and scientists. A modern range also includes highly complex mechanical and electrical systems that ensure accuracy and safety during testing. In addition, test ranges encompass vast geographical regions, such as desert or ocean areas, which are located away from populations. The activities of the people and equipment on the range must be closely coordinated so that meaningful test data results are obtained. The test range must have certain capabilities so it can carry out its mission. These capabilities are overseen by a mission control function.

The primary capabilities of mission control are to coordinate safety, security, communications, frequency management, time and synchronization, flight tracking, data collection, and data processing.

SAFETY

Minuteman III Command Destruct

Safety is of critical importance during a test. Many types of hazards may be present that must be accounted for and limited. SWATS technicians may work closely with Range Safety to assure there are no injuries or mishaps on the Range or surrounding area and that the test environment is a safe one. During certain tests, such intercontinental ballistic missile (ICBM) launches out at Vandenberg AFB, certain critical telemetry information from the is fed to the Range Safety Officer, who is a member of mission control. All safety issues ultimately are the responsibility of range safety. In addition, this office controls the *flight termination system* or *command destruct* system in flight. During the test (during the Boost phase of the mission) the vehicle can be commanded to terminate thrust (effectively destroy) a malfunctioning test missile if it has violated safety rule such as an off course missile.

SECURITY

Some of the items tested are classified or are extremely dangerous (e.g., ICBM and cruise missile subsystems and rocket motors). Some test ranges have classified areas. Range security is there to assure that no unauthorized access occurs.

COMMUNICATIONS

Range communication provides the necessary communication links between the various activities. Reliable communication keeps the test range organizations informed of the progress of tests and other events of interest to them. These communication systems take many forms: LAN, intercom, public address systems, telecommunications, and point-to-point microwave, to name a few.

FREQUENCY MANAGEMENT

Just as a test range's physical space must be controlled, so must its electromagnetic radiation. A given test range may be conducting simultaneous tests but in different spaces. With all of the different tests generating a multitude of signals, frequency management must control the use of frequency, bandwidth, and signal strength so one test does not interfere with another test.

TIME AND SYNCHRONIZATION

During and after a test, it is necessary to have methods for both equipment synchronization and data correlation. For this purpose, range timing transmits time and synchronization signals that are used throughout the range. In addition, these signals are recorded along with the test data. *Equipment synchronization* allows for the exact coordination between all of the electronic systems involved during a test. *Data correlation* allows analysts to determine the time of any event and also the time between any multiple events.

FLIGHT TRACKING

Flight tracking's primary function is to monitor the position of the airborne test vehicle during the test. Position data (such as azimuth, elevation, and distance), velocity data, and acceleration data of the test vehicle are needed by other range activities, such as range safety. Flight tracking uses various equipment and techniques to accomplish its job. Two methods of tracking aerospace test vehicles are through radar (both skin tracking and transponder tracking), from the vehicle and also optical tracking systems. The most popular means of tracking objects on a range is through radar tracking. *RADAR* is the acronym for RAdio Detecting And Ranging. Tracking radar is a key instrumentation asset at nearly every range, since it can provide all weather position data on the test vehicle.

One type of flight tracking radar uses a ground-based transmitter-receiver with a highly directional antenna. The transmitter generates a short-duration, high-power, high frequency (HF) energy pulse. The antenna directs the pulse toward the test vehicle. How long it takes for this pulse of radio-frequency energy to reach the vehicle, reflect, and return depends on the vehicle's distance from the transmitter. The direction in which the antenna is pointing indicates the vehicle's azimuth. Since both distance and direction from a known geographical point (the radar site) are known, a single radar system provides us with test vehicle position information.

Another type of Flight Tracking involves similar radar set up but instead uses a SHF C-Band transponder similar to transponders used on civilian aircraft. This type of RADAR tracking generates highly accurate positional data. Basically the transponder will transmit a response to the radar "interrogation" pulse.

This method of flight tracking is much more accurate than a simple "skin" track. Telemetry inertial guidance information (TMIG) is another method for flight tracking on the range. The vehicle will send via its real-time telemetry it's positional information based on a known launch point. Once the vehicle launches its inertial navigation system senses acceleration along the X, Y and Z-axis. This is the primary tracking method for ICBM testing because it is currently the most accurate.

Finally, the last type of vehicle tracking is through optical tracking. Optical instruments differ from radar in a number of ways. Generally they are passive in that they do not provide an energy source to illuminate the target, but depend on collecting sunlight reflected from the target vehicle. These devices record a sequence of pictures, either on photographic film or videotape, along with the azimuth and elevation angles from the instrument to the object for each picture. Thus, to get the desired position information from the optical data requires a triangulation solution involving several instruments, or the addition of a radar or laser ranger to the optical instrument (range vectors). Optical systems generally only provide the required performance in ranges of 100 miles or less. By using several optical devices along a test vehicle's flight path, range tracking can watch the vehicle throughout its entire flight.

DATA COLLECTION

Another area of R&D is the improvement of data collection systems. Apprentices work with engineers to improve data collection, communication, and data processing systems. Data collection refers to the methods and equipment used to sample and process different kinds of information. Communication refers to the methods and equipment used to transfer information. Data processing or "reduction" refers to the methods and equipment used to process and present information to the user.

The purpose of any test is to determine if the test item can do its job and show where it can be improved. During a test, mission control coordinates the collection of test data from ground and aircraft-based instrumentation and telemetry systems. These systems are used like rulers to measure the performance of the item under test. The data is permanently recorded on magnetic tape and into computer memory so that it can be replayed and processed later on. For a given test, the same data may be collected from several different physical locations. Many tests occur only once, so it is important to be redundant in the data collection process.

DATA PROCESSING

During and after the test, data is retrieved from the instrumentation and telemetry systems, compiled, and analyzed. The data may undergo conversions and format changes before it is interpreted. The information extracted provides engineers and manufacturers with the results of the test. The results are packaged into a formalized test report.
Satellite, wideband, and telemetry journeyman may interact with any of the organizations that provide the test range capabilities just described. However, the primary roles of SWATS personnel are to support the test range mission in the areas of data collection and data processing using instrumentation and telemetry systems.

APPRENTICE ROLE

With this in mind, the SWATS apprentice supporting R&D may construct, modify, and test data collection, communication, and processing systems; this also includes all support equipment. By improving our data collection and processing techniques, we are able to provide accurate, precise data to engineers who play a vital role in the procurement of weapons systems for the DOD.

Block 14, Chapter 6
INSTRUMENTATION AND TELEMETRY SYSTEMS

Instrumentation

This refers to designing, building, and utilizing physical instruments or instrument systems for detection, observation, measurement, automatic control, automatic computation, communication, or data processing. Instrumentation also refers to the group of instruments and auxiliary equipment that supports an experiment, test, or process. To put instrumentation devices or systems into perspective, think of an instrument panel in an automobile. A speedometer is an instrumentation device that measures how fast the wheels are turning to determine automobile speed. The fuel gauge is an instrument used to monitor the amount of fuel in the fuel tank. An example of an instrumentation system is the environmental control system monitoring the temperature level in the passenger compartment to keep it constant (thermostat).

Similarly, instrumentation devices and systems exist around the home. A smoke detector detects smoke from possible fires. If smoke content exceeds a certain level, the smoke detector sounds an alarm. A detector monitoring carbon monoxide levels in the home is another example. There are numerous examples of instrumentation devices and systems in almost every environment.
In the field, technicians monitor similar parameters. Fuel, speed, fuel consumption, vibration, acceleration, voltage levels, and temperatures on aircraft and missiles are all measures of instrumentation devices.

Although you may hear the words instrumentation and telemetry used interchangeably, they have different meanings. Instrumentation is defined as designing, manufacturing, and utilizing physical instruments or instrument systems for detection, observation, measurement, automatic control, communication, or data processing. The term instrumentation is also used for the ensemble of instruments and auxiliary equipment used in an experiment, test, or process, or in a plant, machine, or vehicle.

Since all branches of experimental science and technology depend on instrumentation, specialized instruments, with a corresponding body of knowledge and practice, have been developed separately in many fields. Thus chemical instrumentation, aeronautical instrumentation, medical instrumentation, optical instrumentation, and many other similar terms indicate areas of specialization in various industries or professions.

Instruments are sometimes classified according to the following:

- The field or purpose of application, such as navigation instruments
- According to their functions in instrument systems, such as detection, measurement, recording, computing, controlling, signal modification, or display
- According to the physical quantity or property that is to be measured or controlled by the instrument, such as flow, temperature, pressure, force, displacement, level, acceleration, and electrical qualities (voltage, current, resistance, and capacitance).

Instruments may be found just about anywhere, in your home appliances, automobile, office or shop.

TELEMETRY

The word telemetry is a combination of a pair of Greek words. Tele means far off and Meter means to measure. Hence telemetry means making measurements while far away, or at a remote location. Telemetry began because of the need to make measurements at inaccessible places, like the temperature inside an oven, and grew into a complex science capable of making measurements inside a guided missile, or at any other remote location. For instance, during a Space Shuttle launch real-time data is transmitted during the flight back to analysts on the ground. This data is vital in order to ascertain the health of the vehicle during flight. This data can be used to make decisions on the flight or even to reconstruct events after the fact (such as during the Columbia explosion during reentry). Telemetry systems are can also be found in hospitals. In intensive care units, patients' vital signs are monitored and sent to the nurse's station. With telemetry, nurses can monitor the condition of more than one patient simultaneously. If a vital sign (such as heart rate) meets preset parameters (above or below) an alarm sounds, alerting the nurse staff.

As stated earlier, telemetry measures from a distance. Sometimes phenomena measured by military instrumentation systems are not directly accessible, so telemetry is used to send measured information from an inaccessible area to a control station. With telemetry, technicians we can monitor functions on a missile during a launch from Vandenberg AFB in California to Kwajalein Atoll in the Pacific Ocean; or technicians can monitor data on a guidance system traveling on the rocket-sled track at Holloman AFB in New Mexico.

In traditional Telemetry/Instrumentation jobs the SWATS technician is constantly challenged to be able to satisfy the demands of data acquisition. Measuring an almost infinite variety of physical phenomena provides this challenge. We will now discuss the many different physical phenomena and some of the devices used to monitor them. We will begin by defining some fundamental terms. Then we will explain each of the most common physical phenomena, and then describe the transducer used to convert them to a form we can use in the next stage of the telemetry system.

So let's discuss the first part of a typical Telemetry system, Transducing. *Transducing*, or converting physical phenomena into an electrical signal.

PURPOSES OF TRANSDUCERS

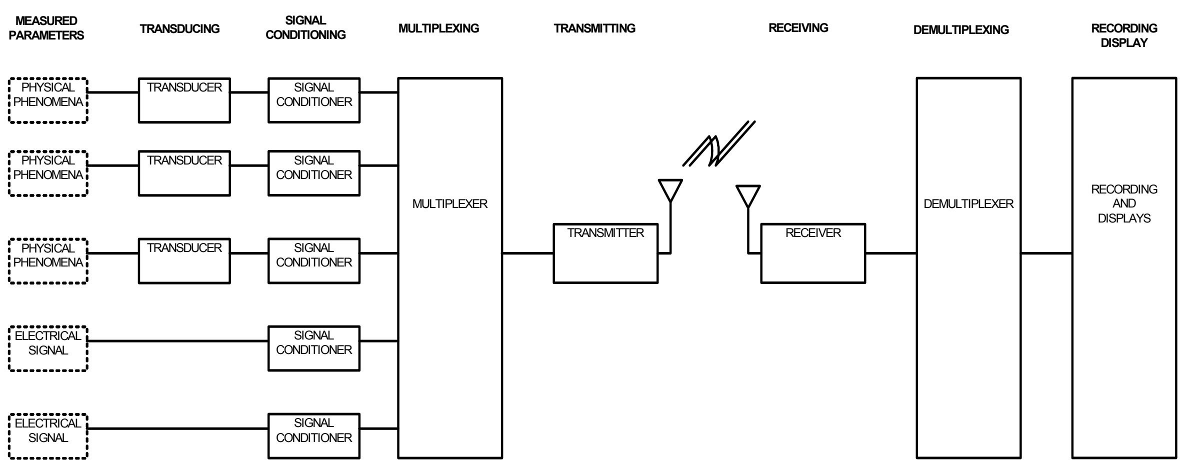
It is the purpose of a **sensor or transducer** to measure some physical property, such as temperature, and to generate a voltage that is proportional to the quantity measured. The input can be any physical property that is measurable, but the output is almost always a voltage. Since the physical property may change over time, the voltage must follow the change. At all times there is to be a direct correspondence between the voltage out of the transducer and the physical measurement. Before we get into the kinds of transducers and how they work let's first define some terminology. A **measurand** is any physical quantity that occurs and is observed and measured. There are two basic approaches to making measurements.

The first method is by **direct comparison**. This is where we compare an unknown magnitude (measurand) against a standard. A *standard* is a precisely known or defined quantity that is regularly and widely used. They are accepted as the universal reference by which everything is compared. For example, physical measurements such as length, time, mass, temperature, electric current, and luminous intensity require standards that allow for a complete and consistent system of physical measurements.

These are developed and maintained by the National Institute of Standards and Technology (NIST) at Washington, DC. An example might be measuring a piece of wood by comparing it with a steel rule. The inch-units on the rule are ultimately traceable to the primary source.

The second method is by **indirect comparison**. This is where we measure an unknown magnitude indirectly by means of a device that converts (tranduces) one physical variable into another before being compared to a standard. An example might be converting heat to a resistance, then measuring the resistance and comparing it against a standard resistance value that represents an exact temperature. To do this, we must have first calibrated that specific transducer against exact temperatures in a controlled environment to create a resistance to temperature conversion scale. As we examine each transducer you will see how the indirect comparison is made.

Before we move on, let's review the whole telemetry system, see fig 6-1. A device or sensor that converts a physical phenomena into a proportional output is called a *transducer*. The transducer is the first part of a measurement system (telemetry system). The transducer's output may not be usable by the multiplexing equipment. Therefore, we need to condition the signal to keep it within voltage and frequency parameters. Now that we have control of the signal, we can convert it to a form suitable for transmission. Convert in this context could mean analog to digital conversion, frequency mixing, or signal encoding. This signal can now be transmitted over a data link, for example, via transmitters, cables, antennas and receivers. Next, we have to undo the conversion that was previously done. Finally, we see a reproduction of the original signal at our display and recording instruments. This signal represents the physical phenomena. The processes of transducing, signal conditioning, multiplexing, transmission and display will be presented throughout this objective.



(Fig 6-1, Telemetry System Block diagram)

Transducers come in all shapes and sizes. They utilize many types of technology, some of which will be presented here. They are the link that binds the physical word to the world of electronics.

DISPLACEMENT AND MOTION

The first type of Transducers we will discuss deal with displacement and motion measurements. These measurements are based on two of the fundamental quantities in nature (length and time). Stress,

pressure, force, and temperature, etc. are often measured by transducing them to motion (changing displacement) then measuring this resulting motion.
The **displacement** of any object can be classified into one of two main types; straight-line, one point to another along a straight line, or rotational, the plane rotation about a single axis.

Straight line displacement is some amount or magnitude of distance between two points, which will be measured as a dimension. This will tell us how far something moved or, how far an object is from a known reference point.

A term associated with straight-line motion is speed. Or, how long did it take to displace? **Speed** is defined as the length of path taken, divided by the amount of time it took you to travel it. Notice that "length of path" has no implied *direction* of motion.

Velocity is a term like speed, but the term displacement is used in the velocity formula (velocity = displacement / time interval). Velocity has an implied direction of motion.
It is often true that speed has the same numerical value as velocity, but direction of motion may not be the same to two different observers.

Acceleration is a change in velocity in a certain amount or unit of time. It represents motion in which the velocity changes from point to point. If a moving object changes the magnitude of its velocity and/or its direction, acceleration occurs. A good example of this would be during ICBM testing. When the missile approaches stage separation it's rate of acceleration slows down even though it's velocity is still rising. This is due to the absence of propellant in the near empty stage.

Speed or velocity can be computed by dividing the distance traveled (feet, inches, kilometers, meters, or centimeters) by the time (hours, minutes, or seconds) it took to travel the distance. Examples are miles/hour and meters/sec.

STRAIN GAGES

The kind of measurement we will look at first is a result of stress on an object. When a force acts over an area it is called stress. Stress is either **tensile** (pulling apart), **compressive** (pressed together), or **shearing** (like scissors action). This stress causes an elastic change to the material. This dimensional change or *deformation* is referred to **strain**.

Strain, a measurement of the deformation of a material, is defined as the change in dimension divided by the original dimension: Strain (ε)=Change in Dimension (ΔL)/Original Dimension (L_1). Strain is either linear (change in length), volumetric (change in volume), or shearing (the result of tangential forces).
To understand linear strain, imagine a weight suspended from a rubber band. The rubber band is stretched to six inches (L_2) from an original length of four inches (L_1). The strain can be calculated by putting the numbers into the earlier defined equation:

$$\varepsilon = \frac{L_2 - L_1}{L_1} = \frac{\Delta L}{L_1} \qquad \text{or} \qquad \frac{6-4}{4} = \frac{1}{2}$$

Measuring stress involves many assumptions and complicated mathematics. For this reason, stress analysis is obtained indirectly from the measurement of deformations or strains using strain-stress relations. At this point, it is enough for you to know that *strain is the result of stress*. Now that you have covered material deformation, lets review some terms:

1. Stress is the force on a body divided over the area over which the force acts.
2. Strain is a change in dimension divided by the original dimension of a body.
3. Elastic deformation is a strain that exists only during the application of stress.

Strain gages supply vital data defining stress and strain parameters of missile, aircraft, and commercial equipment. Strain gages operate on the principle of piezoresistance. *Piezoresistance* is the ability of a material to change its resistance as it is mechanically stressed. In the case of the strain gage, forces stretch and/or compress a high-tensile resistance wire thereby changing its internal resistance. The actual diameter of the wire changes, thereby changing its internal resistance and its ability to carry current. The change in resistance equates to a change in voltage when a current is passed thru.

Strain gages have a property known as *gage factor*, which is a change in resistance that is proportional to the change in length. This also describes the piezoresistive effect, the ability of a material to change resistance as it is mechanically stressed. Strain gages are manufactured with different degrees of sensitivity. Manufacturers of strain gages list individual sensitivities as the gage factor. The gage factor is defined as the ratio of the change in resistance to the ratio of the change in length (strain) along the axis of the gage.

$$GF = \frac{R_1 / R_2}{L_1 / L_2}$$

The larger the value, the more sensitive the strain gage. Most commercial resistance strain gages have a positive gage factor. This means that an increase in strain produces an increase in the strain gage resistance. A strain gage usually forms the active leg of a Wheatstone bridge circuit.

Three types of strain gages will be discussed, bonded, rosette, and semiconductor types. In all three cases, the gages have one or more piezoresistive elements attached (bonded) to a backing film, and then film with the gage is epoxyed to a member to be measured for strain forces.

Bonded Strain Gage (Single element)

The bonded strain gage is by far the most widely used strain measurement tool for today's instrumentation practices. It consists of a grid of very fine wire, or more recently of thin metallic foil, sandwiched between two layers (top and bottom) of thin insulating material. In use, the gage is attached to the test member with adhesive. When the member is loaded (deformed), the strain due to this tension and compression is transmitted to the grid. The grid changes electrical resistance linearly with strain. Single element strain gages are designed to measure only those forces which are parallel to the strain gage axis. Strain applied to the transverse axis is usually so small that it has a negligible effect on the output.

Rosette (Multiple element)

When strain directions are not known or you are required to measure multiple axis strains at a single point it is necessary to use a multiple array of strain gages called a rosette. The rosette is like two or more bonded strain gages built together in one assembly. The individual elements in a rosette gage are arranged to facilitate later calculation of both the magnitude and direction of the principal strains. In a three axis (element) rosette, three different signal conditioning circuits, and three separate channels are required to measure or record the strain data.

Semiconductor Strain Gage

Coming into prominence presently is the use of semiconductor strain gages. The semiconductor strain gage is based on the piezoresistive effect in certain semiconductor materials. The gage element is cut from single crystals of heavily doped silicon. These gages have elastic behavior and can be produced to have either positive or negative resistance changes when strained.

Essentially, the same types of backing, bonding materials, and mounting techniques used for metallic bonded gages are suitable for semiconductor gages. The main advantage is their extreme sensitivity or high gage factor. Their disadvantages are, however, non-linearity, fragility, temperature dependence, and expense.

Strain gages are the basic sensor of many other types of measuring devices such as accelerometers, load cells, and pressure gauges to name a few.

ACCELEROMETERS

Another type of motion transducer is the accelerometer. This device converts velocity variation (acceleration) or vibration into a proportional electrical signal. Vibration is merely acceleration in more than one direction. Typically, acceleration is measured in "g's" or multiples of gravitational pull. Usually acceleration is only measured in one axis (i.e. X, Y, or Z)

There are several types of accelerometers used in industry. The two we will learn about are the most common versions of accelerometers used in the instrumentation field. Both take the form of what is called *seismic mass* or *weighted mass*. The first uses quartz crystals, and the second makes use of the strain gage.

The **quartz crystal type** uses a property of crystals called the *piezoelectric effect*. Quartz is naturally piezoelectric when properly cut. When quartz crystals are subjected to mechanical stress, they produce electric currents; when subjected to an electric voltage, the crystals will vibrate. When used as an accelerometer they are self generating and do not require an external power source.

A crystal properly mounted in a missile will produce changes in charge proportional to velocity changes, thereby measuring acceleration or deceleration. The crystal's rest position is the reference or midrange value. Any acceleration will be shown as a rise in charge, while any deceleration will be shown as a drop in charge. Piezoelectric accelerometers exhibit *high sensitivity*, extreme compactness and they are rugged. For high vibration frequencies, crystal accelerometers are normally used.

PRESSURE AND FORCE

In the everyday world, the terms pressure and force are used loosely to mean the same thing. In instrumentation, you must be a little more careful. Pressure is the application of a force to some object by something in contact with it. Pressure is the measurement of a force divided by the area of the surface upon which it acts. If a ten-pound force is exerted on an area of 5 square inches, then the pressure between the two is 10 pounds per 5 square inches or 2 pounds per square inch. The formula for pressure is: Pressure = Force / Area. Some examples of units of pressure are pounds per square foot and kilograms per square centimeter.

When measuring pressure, the first question is what kind of pressure are we measuring? One concern is whether you want absolute, gage, or differential pressure. **Absolute pressure** (PSIA) is the pressure a fluid exerts if compared to a vacuum. **Gage pressure** (PSIG) is the difference between the pressure being measured and atmospheric pressure. **Differential pressure** (PSID) is the difference between any two pressures. Typically you as a SWATS technician will be dealing with PSIG, in other words you will be trying to ascertain pressures exerted on an object while already accounting for atmospheric pressure.

The next question we must ask is what are we measuring the pressure of? The answer is fluids. In many respects, gases resemble liquids. Since both are capable of flowing, they are commonly referred to as fluids. Two major differences between gases and liquids are compressibility and expandability. Gases are highly compressible, while most liquids are only slightly so. Gases usually completely fill any closed container that they are in, while most liquids fill a container only to the extent of their normal volume. Both gases and liquids exert pressure upon the surfaces with which they come in contact, *but this pressure does not remain constant when the gases or liquids are flowing*

Now that you have a feel for pressure let's talk about force. Everyone has an intuitive conception of what a force is, its like pressure with direction. We think of it as either pushing or pulling something. When a child pulls a wagon, it moves. When we push a door it opens. In most basic terms, a force is any action which changes the state of motion of an object.

By manipulating laws of physics, engineers have designed several transducers to measure force. We may want to measure the force generated by a jet or rocket engine. One of the more common force measurements we take is weight. When we weigh something, we are actually measuring the force that gravity applies to that object.

Note in the equation Force = Mass x Acceleration. The amount of force depends on the mass and the acceleration. By controlling either the mass or acceleration and measuring the other we have two ways to measure force. A specific application of force that we will want to measure is pressure. Pressure is how a force acts over a fixed area. Pressure is proportional to force and inversely proportional to the area over which it acts (Pressure = Force / Area). If we apply force to a thumbtack with a sharp point, it will penetrate a cork bulletin board. If we apply the same force to a 1" diameter dowel, the force will be distributed over a greater area and the dowel will not penetrate the bulletin board.

Sometimes we want to measure a pressure directly. At other times, we will use pressure measurements to determine the force applied too, or perhaps generated by, an object. We can do this two ways. First, by applying the force to some elastic member and then measuring the resulting deformation. Second, by transducing the unknown force to a fluid pressure and then measuring the pressure.

TEMPERATURE

Heat and Cold

Temperature is the measure of the relative hotness or coldness of a body. It is an arbitrary measurement. We consider things to be hot or cold based on our environment as perceived by our nervous system. The relative hotness or coldness of an object, as measured by its temperature, simply indicates in which direction heat will flow. Physical laws state that heat will always flow from a hotter body to a colder body regardless of the masses of the two bodies.

Heat is a form of energy. A hot body has more internal energy than an identical colder body. The two most important effects produced by heat are the change of temperature of an object and the change of the state of a substance. If heat is added to cool water, the water will change temperature. The temperature will continue to increase as heat is added until the water boils. Boiling changes the water from liquid to gas. Except for certain substances, heat causes most matter to expand and cold causes matter to contract. Temperature changes might also alter the electrical, magnetic and optical properties of a substance.

Scales

We use the temperature of an object to determine the hotness or coldness of it. The temperature is related to three common scales. The first scale, named after a German physicist is called Fahrenheit (F). The point where water freezes is 32 degrees and the point where water boils is 212 degrees. The next scale was devised by a Swedish astronomer and is called Celsius (C). On this scale, the freezing point of water is 0 degrees and the boiling point is 100 degrees. A third scale called Kelvin (K) is an absolute, or thermodynamic temperature scale. The Kelvin scale uses the same size unit as the Celsius scale, but is indexed so that 0K is equal to absolute zero, theoretically the lowest possible temperature. It is based upon the Celsius scale with 100 units between the freezing point and boiling point of water where 0°C = 273.15K and 100°C = 373.15K. Note also that "kelvins" is a unit, and we never use the term "degrees Kelvin." To convert between Fahrenheit and Celsius, we can use the formulas °F = 9/5 °C + 32 and °C = (°F - 32) 5/9.

Transfer of Heat

There are three different ways heat passes from a hot body to a cold one. They are: conduction, convection, and radiation. **Conduction** occurs when heat is transferred between two objects in direct contact with each other because of a temperature difference. For example, a spoon in a hot cup of coffee will get hot. **Convection** is heat transferred by movement of heated liquid or gas. When you place your hands over a campfire, they are heated by convection. The fire warms the air; the air rises, and your hand is warmed by the warm air. **Radiation** is the third process by which heat can reach you. The source of the heat produces electromagnetic waves, like light, which travels through empty space where they strike you and warm you. You cannot touch the sun, but its radiation warms you. Notice that radiation does not require direct contact between substances.

Within testing and evaluation, temperature measurement may be required in many areas such as surface or skin, engine exhaust, and air temperatures throughout a test package. The transducers used for temperature measurement include bimetals, thermoresistive and thermocouples.

BIMETAL TEMPERATURE SENSING

When two metal strips of equal size are brazed together and they each expand at a <u>different</u> rate as temperature changes (coefficient of expansion), they will physically deflect as the temperature increases or decreases). The sensing strips are commonly found in six different forms. Such bimetal strips from the basis for control devices such as the common home heating system thermostat. They are also used to some extent for temperature measurement.

Thermometers with bimetallic temperature-sensitive elements are often used because of their ruggedness, ease of reading, and convenience of their particular form.

THERMORESISTIVE DEVICES

Other types of transducers used for temperature sensing are the thermoresistive type. Actually, there are two distinct devices, but they work on the same principle. They are the resistance temperature detector (RTD) and thermistor.

RTD's operate on the principle that the resistance of metal varies with changes in temperature. A typical probe uses platinum, nickel, or copper wire wrapped around an insulator an enclosed in ceramic. RTD's have a positive temperature coefficient, meaning as temperature increases, resistance increases. The resistance change per degree is small, but they are very stable. RTD's have low sensitivity but are linear over a wide range and can, therefore, be used in applications where the temperature spans are very wide. RTD's also have a high temperature operating range.
Like the RTD, the **thermistor** is also a temperature sensitive resistor. The word that best describes the thermistor is sensitive. The thermistor exhibits, by far, the largest resistance change with temperature. A 4%-6% change in resistance per degree is common. Thermistors are generally composed of semiconductor materials and like RTD's, come in many shapes, Although positive temperature coefficient units are available, <u>most</u> thermistors have a negative temperature coefficient; that is, as temperature increases, resistance decreases.

Thermistors are extremely non-linear but they can be made very small which means they will respond quickly to temperature changes. They are typically used for precision temperature measurements within a limited temperature range.

Since RTD's and thermistors are not self-powered, a current must be passed through the device to provide a voltage that can be measured. This current can cause *self-heating* within the device, thus changing its temperature. The device will generate heat and measure itself. To reduce self-heating errors, use the minimum amount of current that will give you the resolution you require, and use the largest device that will give you good response time. Obviously, there are compromises to be considered.

THERMOCOUPLES

Thermocouples are devices, which measure heat. A thermocouple is formed when two different metals are connected to form a junction and create *galvanic action*. Galvanic action produces voltages and can, therefore, cause electrical currents in the same way as wet and dry cell batteries. When two dissimilar metals are connected together by twisting or bolting, the different atomic characteristics of each metal establishes a voltage across the metals' junction. The actual potential developed is very small, but it is directly affected by the temperature of the junction. When exposed to varying temperatures, the junction's varying voltage induces corresponding currents in any complete electrical circuit connected across the junction. The galvanic action can be employed to produce a temperature sensitive transducer, i.e., a thermocouple

Thermocouples can be used over a wide range of temperatures. Although a given thermocouple is not linear over a complete range, each type can be found to give you a partial linear region. Thermocouples are much more rugged than thermistors or RTD's. They can be manufactured on the spot by soldering or welding and you don't have self-heating problems like with thermistors and RTD's.

TRANSDUCER CHARACTERISTICS

In addition to selecting the proper type of transducer for the application, one must consider the following six characteristics.

1. Suitability for the expected environment—The transducer must perform its specified function with a minimum of extraneous error-causing external influences. For instance, a piezoresistive strain gage transducer that converts mechanical stress into proportional voltage may have its measurement influenced by increased temperatures in the test environment.

2. Magnitude of the electrical output—The transducer's range must be great enough to get the desired measurement resolution. For example, for a given input, a more sensitive transducer produces a greater output voltage than a less sensitive transducer.

3. Frequency range—All transducers are bandwidth-limited. The bandwidth (frequency response) of each transducer must be sufficient for the frequencies of the expected measurement.

4. Impedance—Low impedance transducers should be used whenever possible to reduce the shunting effect on the telemetry system's input.

5. Excitation—A transducer may require excitation from the telemetry system. This adds additional circuitry, power demands, and cabling requirements.

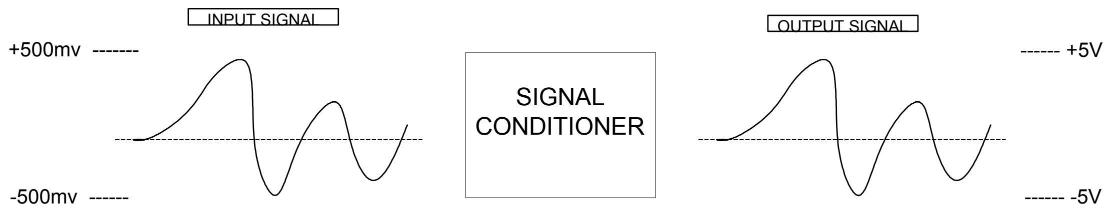
6. Accuracy—One must consider how accurate the transducer's measurement will be as shown by its linearity, hysteresis, sensitivity, frequency response, temperature performance, and repeatability.

Typically, the kinds of transducers used in telemetry systems measure acceleration, pressure, displacement, altitude, airspeed, temperature, shock, vibration, stress, strain, rate of climb, pitch, roll, yaw, fuel flow, air flow, force, weight, light intensity, thrust, humidity, voltage, current, frequency, etc. In order to effectively make these measurements, transducers require the help of additional signal conditioning circuitry. In most cases, when the SWATS technician works the acquisition side of the telemetry system, he is heavily involved with transducers.

SIGNAL CONDITIONERS

Now let's discuss Signal Conditioning, or converting an electrical signal to a form suitable for multiplexing or transmitting. As we have learned previously, transducers convert measured phenomena to proportional output voltages. The transducer's output (voltage, current, resistance, charge, capacitance, etc.) is not, in many cases, compatible with the remainder of the instrumentation package. Therefore, the transducer's output signal may have to pass through several steps of processing before they are in the proper condition for multiplexing or transmission. The first step in this process is signal conditioning.

The phrase "signal conditioning" implies that some electrical signal is not quite right for the circuit that follows and subsequently needs to be conditioned. The definition of signal conditioning, as it applies to instrumentation, is modifying the transduced signal into a form usable by the next stage of a measurement system. Once a physical phenomena has been detected and transduced, it is usually necessary to modify the signal before it is in a form that is able to drive an indicator or recorder, see fig 6-2. The output of signal conditioners is almost always voltages that vary proportionally to their inputs.



(Fig 6-2, Signal Conditioner input vs output)

Types of Inputs

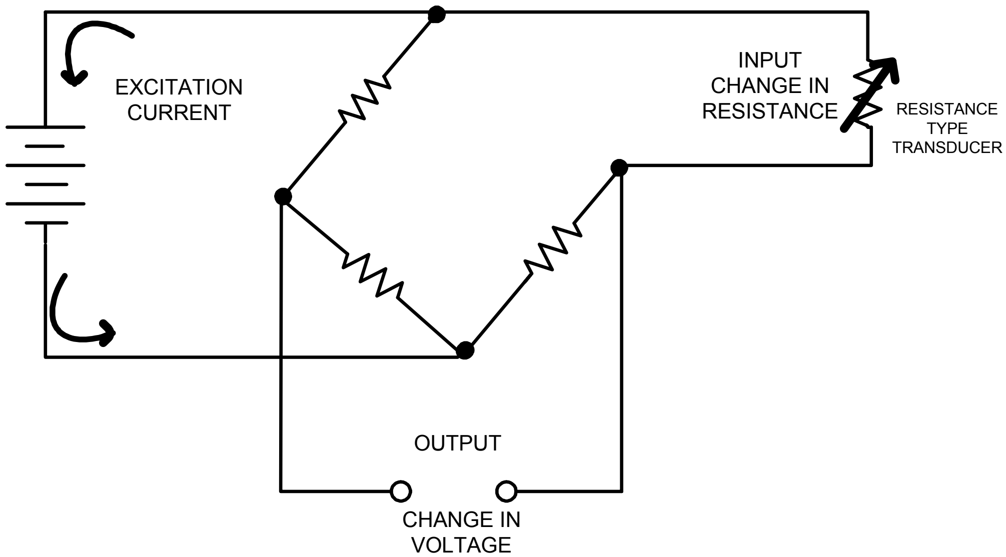
One source of input to a signal conditioner can be from a transducer. Transducers can be categorized into two general types: **passive** (non-generative), those that require an external source of energy, and **active** (generative), and those that are self powering.

A simple bonded strain gage or a thermistor is examples of passive transducers. Transducers of these types require electrical energy for power. Think of them as a passive component (resistor, capacitor, or inductor) in an electrical circuit.

The crystal accelerometer and the thermocouple are active and generate their own energy independently. We do not need a power supply or generator in order for them to produce a signal. Think of them as a battery or generator in an electrical circuit.

Another type of input sent through a signal conditioner may not originate from physical phenomena but from another electrical circuit such as a power supply. Some of the information (data) monitored with the telemetry system will be from other electrical systems. This could include AC and DC power supplies, timing signals, electrical impulses from a device being tested or any data already in electrical form. Remember, regardless of where the signal came from, we just want to prepare it for the next stage of the telemetry system.

Another purpose of signal conditioning is to provide power to energize those passive transducers. This power is called **excitation voltage**. Passive transducers require special arrangements to introduce the energy necessary to make them operate. The particular arrangement required will depend on the operating principle involved. For example, resistive pickups may be powered with a DC source, whereas capacitive and inductive types require an AC source. Excitation voltage must be regulated (that is, constant and stable,) in order for the transducer to operate properly, see fig 6-3.



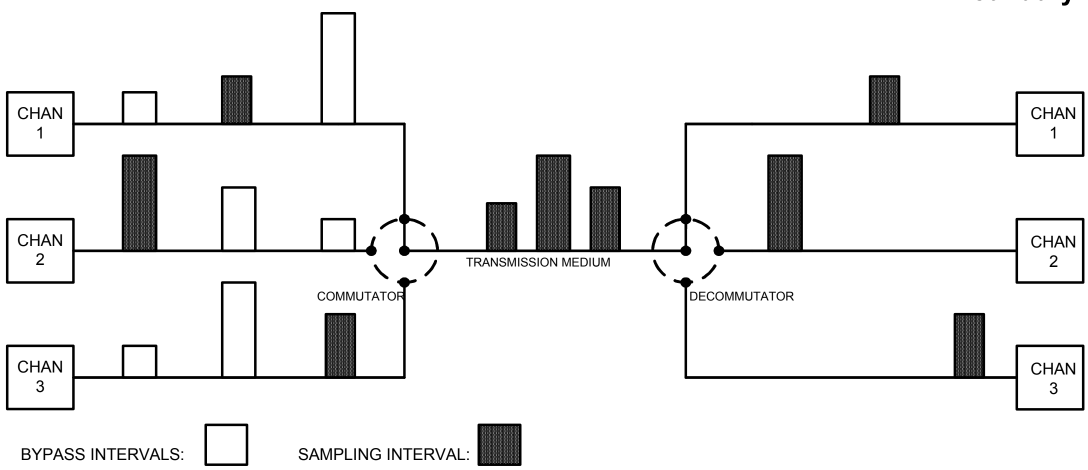
(Fig 6-3, Bridge Circuit Excitation)

Measurement System

You can see in the simplified telemetry system (Fig 6-1) that the information to be recorded comes from physical phenomena that have been transduced into electrical signals, and from sources that are already in an electrical form. Both require signal conditioning in order to modify the signal so that the conversion and multiplexing section can receive the data. Notice that there may be several stages of signal conditioners combined together. Each stage will affect the signal in some specific way. Several stages used together, for example, could convert the output of a strain gage (varying resistance) to a proportional DC voltage that swings from 0 to 5V. Converting the signals to the range of 0 to 5 VDC or $\pm$ 2.5 VDC is a goal of some telemetry systems. The reason for this is because the next section will multiplex (mix together) and convert many sources of data. Usually analog data from the signal conditioner is first sent to a subcarrier oscillator (SCO). SCO's require a signal that varies $\pm$ 2.5 VDC. They convert the varying DC voltage to a proportional varying frequency (FM).

MUTIPLEXORS

Multiplexing is a method of packing a number of measurements into a single telemetry data stream. Time division multiplexing is the most common method of multiplexing used in telemetry. Time division multiplexing is a means of time-sharing the available RF link between the various transducers. All channels of transducer data use the same portion of the frequency spectrum, but not at the same time. The signal on each channel is sampled in sequence by an electronic device called a *commutator* (fig. 6-4). When all channels have been sampled, the sequence starts over with the first channel. Thus, samples from a particular channel are interleaved in time between samples from all the other channels.



(Fig 6-4, Basic Time Division Multiplexing)

The sampling rate in a typical time division multiplexing telemetry system is at least five times the highest frequency component in the sampled signal. For instance, if the highest frequency sampled is vibration data at 60 kHz, the commutator sample rate would be 300 kHz. The entire time division multiplexing process is a parallel to serial conversion, where the parallel inputs of data may be both analog and digital, and the serial output is a bit stream of 1s and 0s divided into words and frames. A word is a grouping of bits that represents one sample of a channel of data. A frame is a grouping of words that additionally contains a unique synchronization pattern. Frames are structured with synchronization patterns to allow the data to be reconstructed in the proper order at the telemetry reception site.
The most common type of time division multiplexing used in telemetry is PCM. The piece of telemetry equipment that produces PCM is called a *multiplexer-encoder.* Within the multiplexer-encoder, analog transducer data is sampled by a commutator and then converted to a binary number whose value is proportional to the amplitude. The binary number is a number of bits, or 1s and 0s, as determined by an ADC. Additionally, digital data from sources other than transducers may be input and multiplexed along with the digitized transducer data. It is at this point that frame synchronization patterns are multiplexed with the data also. The final output of the multiplexer-encoder is encoded into a serial stream of 1s and 0s in a standard PCM format, typically non-return to zero-level, that is ready for transmission.

DEMULTIPLEXING

Demultiplexing is the reverse process of multiplexing. The entire time division demultiplexing process is a serial to parallel conversion, where the serial input is a PCM bit stream grouped into words and frames, and the parallel outputs are separate channels of both analog (transducer) data and digital data. Primarily, two pieces of telemetry equipment perform the PCM time division demultiplexing process, a bit synchronizer, and a decommutator (also called a frame synchronizer). The *bit synchronizer* basically performs signal conditioning, locks onto the incoming data bit rate, and reconstructs the serial PCM data stream. The idea is to “clean up” the noisy, jittery, and distorted PCM data coming from the receiver and produce error free “clean” PCM data for recording and for sending to the decommutator. The *decommutator*, operating at the PCM bit rate, basically locks on to the synchronization patterns to identify and separate (demultiplex) individual data channels (words). Remember that a word is a group of bits that represents one sample of a measurement channel.

The decommutator, operating at exactly the same frequency as the commutator, demultiplexes and distributes the parts of the multiplexed signal to the proper output channels.

TRANSMITTERS AND RECEIVERS

TRANSMITTING (TRANSMITTERS AND ANTENNEA)

In the simplified overview of transmission system, a measurement from a sensor, such as a pressure transducer, is made and the data is either sent by itself, or more likely, jointed with other measurements through multiplexing into a stream of measurements to be transmitted to a remote location, usually a ground station. If the composite data signal is digital in nature it may be encrypted to make the telemetry transmission unreadable by anyone without the proper decryption key. The data stream is sent to the transmitter where it modulates a Radio Frequency (RF) carrier signal. The carrier signal is then sent to the transmitting antenna where it is radiated into free space. In most cases these components are physically combined into a single telemetry unit, sometimes referred to as a Telemetry package, designed specifically for a vehicle.

The telemetry transmitters produce the RF energy that enables the telemetry data to reach the reception site. The principle types of modulation used with telemetry transmission are frequency modulation (FM) and phase modulation. The UHF L-band frequencies from 1435–1525 MHz are allocated for telemetry testing manned and unmanned aerospace vehicles, while the S-band frequencies from 2200–2290 MHz and upper S-band frequencies from 2310–2390 MHz are allocated for telemetry testing only unmanned aerospace vehicles. Output power of the transmitter ranges from milliwatts not to exceed 25 watts. Telemetry systems that transmit bandwidths less than 1 MHz are considered standard bandwidth signals, whereas those transmitting bandwidths greater than 1 MHz are considered wide bandwidth signals. A low-pass filter, called a *premodulation filter*, is used at the input to the telemetry transmitter to limit modulation frequencies, or bandwidth of the data signal and, thereby, limit radiated frequencies outside the desired operating spectrum.

The antenna on the test vehicle must generally be low cost, lightweight, and robust to survive operation in an extreme environment. The RF frequencies used for telemetry are generally sufficiently high so that line of sight propagation is required. The vehicle antenna must be such that it can send a signal to the receiving station or a relay platform regardless of the orientation of the vehicle. This generally mandates an omnidirectional antenna which radiates equally in all directions and by definition has a gain of 0 dbi. More than one antenna and an appropriate power divider must be used for some vehicles to insure coverage during all vehicle maneuvers. Large wings on aircraft can block an antenna during aircraft maneuvers. The antennas used are usually close to omnidirectional, having low gain in the order of 4-5 dbi. If the telemetry source is a moving vehicle, such as an airplane or rocket, generally omnidirectional transmission antenna is appropriate. It can transmit to the receiving antenna regardless of the orientation of the vehicle on which it is mounted. Aircraft typically use a short dipole mounted on the bottom of the vehicle to cause minimum drag. Missiles typically use a conformal (wrap around) antenna that is part of the skin for the same purpose. If the telemetry source is deep space where transmitter power is limited and the distance is great, a steerable antenna on the vehicle is pointed to the earth station. When a vehicle under test, such as an aircraft, maneuvers into a variety of positions during a test, two or more transmitting antennas may be mounted (top and bottom) so that at least one antenna has a direct line-of-sight path to the receiving antenna under any maneuver conditions.

It is important to note that up to this point in the telemetering process (transducing, signal conditioning, multiplexing, and transmitting), that for destructive type tests this circuitry and equipment is designed to be lightweight, compact, and disposable. For example, an instrumented ICBM has limitations on weight and space, and at the conclusion of the test will be destroyed.

RECEIVING (ANTENNEA AND RECEIVERS)

The antenna on the test vehicle must generally be low cost, lightweight, and robust to survive operation in an extreme environment. The RF frequencies used for telemetry are generally sufficiently high so that line of sight propagation is required. The vehicle antenna must be such that it can send a signal to the receiving station or a relay platform regardless of the orientation of the vehicle. This generally mandates an omnidirectional antenna which radiates equally in all directions and by definition has a gain of 0 dbi. More than one antenna and an appropriate power divider must be used for some vehicles to insure coverage during all vehicle maneuvers. Large wings on aircraft can block an antenna during aircraft maneuvers. The antennas used are usually close to omnidirectional, having low gain in the order of 4-5 dbi.

Antennas are designed with a specific polarization characteristic. The polarization of the antenna determines the orientation of the electromagnetic waves radiated. For maximum efficiency, the polarization of the transmission and reception antennas must be matched. If the test article has a vertically polarized antenna the reception antenna should also be vertically polarized. If there is a mismatch in polarizations between the transmission and reception antennas, energy transfer will decrease and will reach zero if there is an orthogonal mismatch.

A problem arises when the item under test maneuvers relative to the reception site. In addition to shading the transmitting antenna, this maneuvering will also cause the polarization of the transmitting antenna to change relative to the reception antenna. One way to lessen this problem of polarization mismatch is to make the polarization of the reception antenna circular and use a diversity combiner. A *diversity combiner* circuit is used to combine the outputs of the two different polarization receivers. This is a proven effective means of avoiding telemetry signal loss because of polarization mismatches between transmitting and receiving antennas that are caused when the text vehicle maneuvers during a test. If the reception antenna feed has both right-hand-circular and left-hand-circular polarizations, the nulls in signal strength to the receiver can be minimized.

Receiving antennas are selected based upon the amount of gain, directivity, and beamwidth the application calls for. The most common type of antenna for medium to long range telemetry reception is the dual-axis (azimuth and elevation) parabolic dish automatic tracking antenna. However, other types of antennas such as single-axis tracking parabolic dish, omnidirectional, helical, and phased array antennas each serve their applications. Ensuring that the polarizations of the transmitting and receiving antennas stay matched to provide maximum signal transfer is not always possible. A test vehicle's antenna polarization will change relative to the ground station as it maneuvers, and complete signal losses are not unusual. For this reason, many reception antenna feeds contain elements to receive two polarizations, typically righthand-circular and left-hand-circular. This similar in operation to the OMT or Ortho Mode Transducer you learned about in an earlier block of instruction. Some telemetry receivers are actually two separate receivers. One receiver and the appropriate antenna feed are designed to receive one polarization, vertical, and the other is designed to receive the orthogonal polarization, horizontal.

Regardless of whether diversity combining is used, the telemetry receiver must accept the RF signals from the antenna, down convert the RF to IF, and demodulate the carrier to obtain the telemetry baseband signals. The typical telemetry receiver is a superheterodyne receiver with one or more IF stages to provide the required performance.

Within the telemetry receiver, the RF tuner is designed to receive L-band and S-band frequencies.

RECORDING AND DISPLAYING DATA

Telemetry data may be recorded at several points throughout the receiving and demultiplexing. The first place data may be recorded is at the telemetry receiver's 3rd IF output. At this point, data is modulating the 3rd IF. The additional IF developed is referred to as pre-detection or pre-d. The reason for pre-d recording is to capture and store data, as near to its source as practical, to guard against the possibility that equipment malfunction or misadjustment in the ground station will render the data impure or totally unusable.

The second place data that may be recorded is from the telemetry receiver video amplifier's output. This is referred to as post-detection or post-d recording. At this point, the data is a serial PCM signal encoded in the format that was originally transmitted (normally Non Return to Zero-Level). The third place telemetry data may be recorded at the bit synchronizer's output. The bit synchronizer outputs a clean serial PCM code; typically either randomized non-return to zero-level or Bi-phaselevel (Biö-L), specifically designed for recording. This type of magnetic tape recording is known as serial high-density digital recording. This method of recording digital data uses one recording channel. Optionally, the serial PCM code could be converted to a parallel format and recorded on multiple recorder channels. This type of magnetic tape recording is known as parallel high-density digital recording.
The fourth place telemetry data may be recorded is at the decommutator's output during the processing stage. At this point the data has been *formatted* from a serial PCM bit stream into serial or parallel digital data words. Formatted data recording can be done using a number of devices including magnetic tape recorders, floppy disk drives, and hard disk drives.

Displays are used to present telemetry data to the user in a way that allows assessment of whether the vehicle is operating properly. Data can be displayed in several ways, involving strip chart recorders, tabular formats, and graphic displays.
Strip chart recorders are analog type devices where data is presented on paper, with the paper continuously advancing under a marking device such as an ink pen or heated wire stylus.
More modern techniques use heat sensitive paper with a thermal array, or light sensitive paper with a fiber optic array.

OTHER DISPLAYS

Normally, while a test is being conducted, two groups of people look at the displayed data. One group is composed of technicians, engineers, and analysts who know the intimate workings of the vehicle and want to look at measurements to determine if things are working the way they were designed.
The second group of people who are interested in the display of telemetry data are the range safety personnel. They need to know the condition of the test vehicle from a safety perspective. They might want to see a display of vehicle pitch, roll, and yaw that could indicate a problem with the vehicle staying in its assigned space on the test range.
Telemetry systems can be quite simple or extremely complex, but the fundamental processes remain the same. As a satellite, wideband, and telemetry systems journeyman, assigned to a test range mission you will be required to fabricate, operate, and maintain instrumentation and telemetry systems. These systems allow you to collect and process the critical data that is required by the mission.